Human & Robotic Exploration

FY2002 Group 1 Revolutionary Aerospace Systems Concepts (RASC)

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  - **Advanced In-Space EVA Capabilities**
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  - **Life Detection Requirements Definition and Revolutionary Instrument Concept Development**

Human/Robotic Exploration Objectives

- **Human & Robotic Exploration Objective:**
  - **Identify revolutionary architectures, concepts, and key technology requirements for Human and Robotic systems which have the potential, when synergistically combined, to reduce the time, distance and safety barriers associated with scientific exploration beyond Low Earth Orbit (LEO)**

- **Rev·o·lu·tion·ar·y adj.**
  - **. . . Characterized by or resulting in radical change.**

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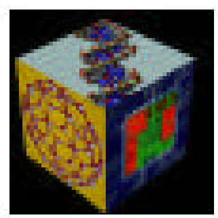
Goal Three: Pioneer Technology Innovation

NASA's GOAL IS TO ENABLE A REVOLUTION IN AEROSPACE SYSTEMS.

In order to develop the aerospace systems of the future, revolutionary approaches to system design and technology development will be necessary. Pursuing technology fields that are in their infancy today, developing the knowledge bases necessary to design radically new aerospace systems, and performing efficient, high-confidence design and development of revolutionary vehicles are challenges that face us in innovation. These challenges are intensified by the demand for safety in our highly complex aerospace systems. The goal to Pioneer Technology Innovation is unique in that it focuses on broad, crosscutting innovations critical to a number of NASA missions and to the aerospace industry in general.



Technology Innovation: Develop revolutionary technologies and technology solutions to enable fundamentally new aerospace system capabilities and missions

Objective 10: Within 10 years, integrate revolutionary technologies to explore fundamentally new aerospace system capabilities and missions; and within 25 years, demonstrate new aerospace capabilities and new mission concepts in flight.

FY2001 Study Activity Results

- **Universities Space Research Association (USRA) Task Objectives:**
  - **Engage a broad audience for solicitation of creative/revolutionary ideas**
  - **Use a collaborative effort of academic, industrial and government experts to identify potential revolutionary aerospace systems concepts for scientific exploration beyond LEO with both Humans and Robots**
  - **Gain an initial understanding of the revolutionary technologies associated with these Human and Robotic systems concepts which would, if developed, maximize the probability of meeting NASA's Exploration Grand Challenges**

FY2001 Study Activity Results (continued)

- **Conducted a NASA-style Request for Information (RFI) through the *NASA Institute for Advanced Concepts* (NIAC) in order to solicit ideas from academic, industrial and government experts**
  - **Received 22 RFI responses**
  - **Responses available at http:// and Appendix A of the Workshop report**

- **Responses covered a number of potentially revolutionary concepts for technologies and systems over a broad range of applications including:**
  - **Extravehicular activities**
  - **Architectures for Human/Robotic planetary bases and planetary exploration**
  - **Infrastructure for optimizing Human/Robotic collaboration**
  - **Transportation and propulsion**
  - **In-situ resource utilization**
  - **Mediation of the effects on humans of low-gravity and illness during long duration missions**
  - **Self-transforming, metamorphic, and self-designing robots**
  - **Aerial robotic vehicles**

FY2001 Study Activity Results (concluded)

- **Sponsored the ICASE/NASA LaRC Workshop on Revolutionary Aerospace Systems Concepts for Human & Robotic Exploration of the Solar System on November 6-8, 2001 in Hampton, VA**
  - **100+ University, Industry, and Government attendees**
  - **Workshop covered current, near-term, and future architectures, concepts, and technologies for Human, Robotic, and Human/Robotic Collaborative exploration of the solar system**
  - **Workshop report currently undergoing final technical editing**
    - Issues and Recommendations
    - Human Exploration from the University, Industry, and Government perspective
    - Robotic Exploration from the University, Industry, and Government perspective
    - Human/Robotic Collaboration from the University, Industry, and Government perspective
    - Revolutionary Technologies
    - RFI Responses

FY 2002 Activities

- **4 Study activities were planned for FY2002**
  - **Human/Robotic Exploration Advanced Concept Development Using Revolutionary Aerospace Systems (Cirillo/LaRC)**
    - Science exploration requirements development based on NASA Grand Challenges
    - Scenario development
    - Concept development (NASA/USRA)
    - Revolutionary Technology Identification
  - **Human and Robotic Cooperative Teams Beyond LEO (Weisbin/JPL)**
    - Focus on hybrid Human/Robotic system architectures
  - **Advanced In-Space EVA Capabilities (Kosmo/JSC)**
    - Focus on in-space EVA capabilities to enhance operations through improved space suit flexibility with associated technology roadmap
  - **Human Emplacement of Lunar Telescopes (Duke-CSM)**
    - Assess effectiveness of astronomical telescopes on the Moon and their optimum design features
- **1 Additional study added in November 2001**
  - **Life Detection Requirements Definition and Revolutionary Instrument Concept Development (McKay/JSC)**

Planned FY 2002 Activities (continued)

- **Human/Robotic Exploration Advanced Concept Development Using Revolutionary Aerospace Systems**
  - **Study Lead: Bill Cirillo, LaRC [Original proposal submitted by Melvin Ferebee]**
  - **Objective(s):**
    - Identify potential revolutionary systems concepts to meet NASA mission requirements
      - **Identify potential beneficial linkage between Human and Robotic missions**
    - Identify and assess potential revolutionary technologies based on revolutionary systems concepts, RATS inputs, etc.
    - Focus for FY 2002 is on:
      - **NanoBioLogic systems for both Human and Robotic missions**
      - **Reusable nuclear transportation systems**
      - **Enhanced In situ resource utilization and in situ science investigations**
    - Identify NASA mission specific needs/areas that are not addressed by outside agencies/companies/universities
    - Integrate results of parallel Group 1 studies

Approach

- **Definition of Top-Level Requirements as decomposed from:**
  - **NASA Vision**
  - **Enterprise Strategic Plans**
  - **NEXT activity**
  - **Established "Search for Life" as primary science mission driver**
- **Decomposition of Top-Level Requirements into measurable objectives**
  - **Probability of Crew Survival**
    - Instantaneous Loss of Crew [Acute]
      - **Based on JSC Human Rating requirements**
    - Long-term impact to crew health resulting in Loss/Permanent Disability of Crew [Latent]
      - **Based on Bioastronautics defined risks**
      - **Based on NEXT HSSWG requirements**
  - **Probability of Mission Success**
    - Science Success
    - Performance Success
  - **Probability of Technical Development Success**
    - TRL [portfolio of SOA, advanced, and revolutionary technologies]
    - 2025 Mission Timeframe for Human missions to Mars
- **Coupled Science Drivers with THREADS WBS to create linkage between requirements, mission architectures, and technology areas**
- **Establishment of Mars Mission options**
- **Establishment of Mission Phases**

Approach (concluded)

- Identification of Risks by Mission Phase
- Definition of Functions/Elements within each Mission Phase
- Development of preliminary risk model
- Preliminary Identification of Risk Mitigation options by Mission Phase
  - Architecture level options
  - Concept level options
  - System level technology level options

- Focus is on robotic enhancements as a primary risk mitigator for both future Human and Robotic missions

- Assess difficulty of achievement using a quantitative TRL method derived from SLI activity

Science-Driven Process

NASA's VISION

To Improve Life Here — To Extend Life to There — To Find Life Beyond

NASA's MISSION

To understand & protect our home planet — To explore the universe & search for life

To inspire the next generation of explorers

Enterprise Strategic Plans

OSS Themes & Missions (S) — OSF Themes & Missions (M)

OAST Themes & Missions (R) — OBPR Themes & Missions (U)

Science Goals & Requirements

Human-Robotic Mission Requirements

Revolutionary Technology Concepts

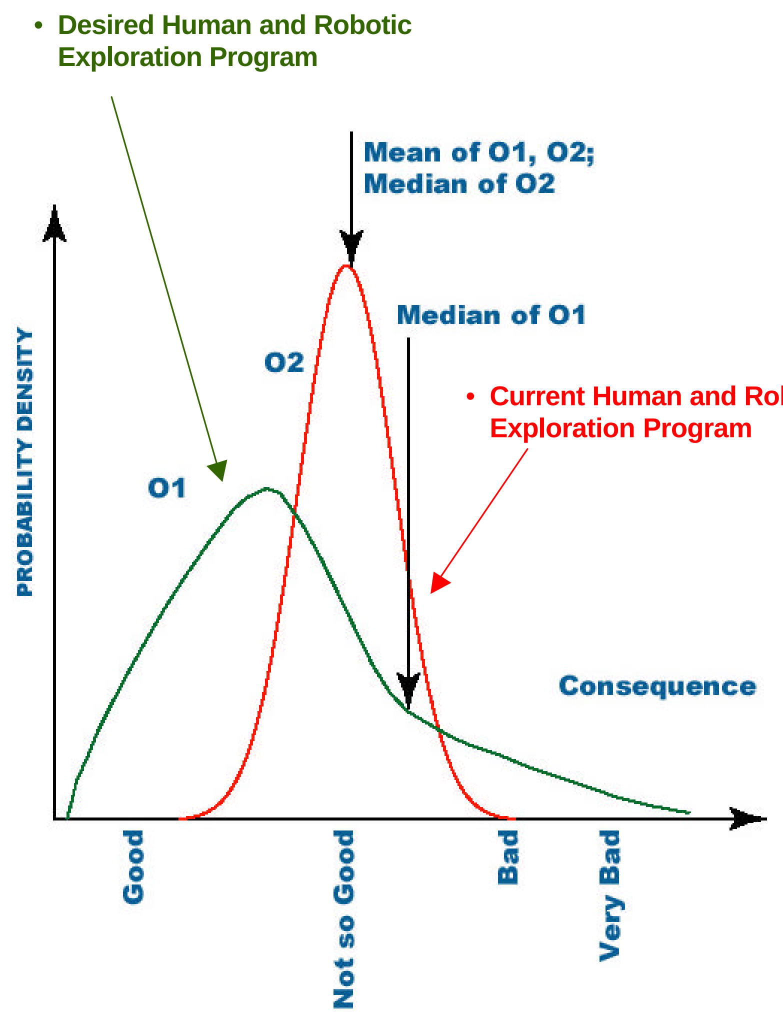
Top-Level Mission/System/Technology Linkage

Vision	Science Questions	Pursuits	Activities	Destinations
Exploration of Life in the Universe	• How did the Solar System evolve?	• History of major Solar System events	• Planetary sample analysis: absolute age determination "calibrating the clocks"	• Moon • Mars • Asteroids • Venus
	• How do humans adapt to space?	• Effects of deep space on cells	• Measurement of genomic responses to radiation	• Beyond Van Allen belts
	• What is Earth's sustainability and habitability?	• Impact of human and natural events upon Earth	• Measurement of Earth's vital signs "taking the pulse"	• Earth orbits • Libration points
	• Is there Life beyond the planet of origin?	• Origin of life in the Solar System • Origin of life in the Universe	• Detection of bio-markers and hospitable environments	• Mars • Europa • Titan • Cometary nuclei • Libration points

	NGST	TPF	Cometary Mission	Outer Solar System	Asteroids	Moon	Mars
…odeling							
	X	X	X	X	X	X	X
						X	X
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
	X	X	X	X	X	X	X
…rchitectures	X	X	X	X	X	X	X
…ogy							
			X	X	X	X	X
			X	X	X	X	X
			X	X	X	X	X
				X	X	X	X
				X	X	X	X
				X	X	X	X
2.2 Space Utilities and Power							
2.2.1 Solar Power Generation					X	X	X
2.2.2 Nuclear Power Generation				X	X	X	X
2.2.3 Wireless Power Transmission					X	X	X
2.2.4 Power Management and Distribution					X	X	X
2.2.5 Energy Storage				X	X	X	X
2.2.6 Cryogenic Propellant Depots				X	X	X	
2.2.7 Thermal Materials and Management				X	X	X	X
2.2.8 Structural Concepts and Materials	X	X	X	X	X	X	X
2.2.9 Space Environmental Effects	X	X	X	X	X	X	X
2.2.10 Technology Flight Experiments	X	X	X	X	X	X	X
2.3 Habitation, Bioastronautics and EVA							
2.3.1 Advanced Habitation Systems				X	X	X	X
2.3.2 Advanced Life Support Systems				X	X	X	X
2.3.3 Environment and Control				X	X	X	X
2.3.4 Human Factors and Habitability				X	X	X	X
2.3.5 Adaptation and Countermeasures				X	X	X	X
2.3.6 Space Medicine and Health Care Systems				X	X	X	X
2.3.7 Biological Risk Prediction and Mitigation				X	X	X	X
2.3.8 Biological Systems				X	X	X	X
2.3.9 Extravehicular Activitiy Systems				X	X	X	X
2.3.10 Technology Flight Experiments				X	X	X	X

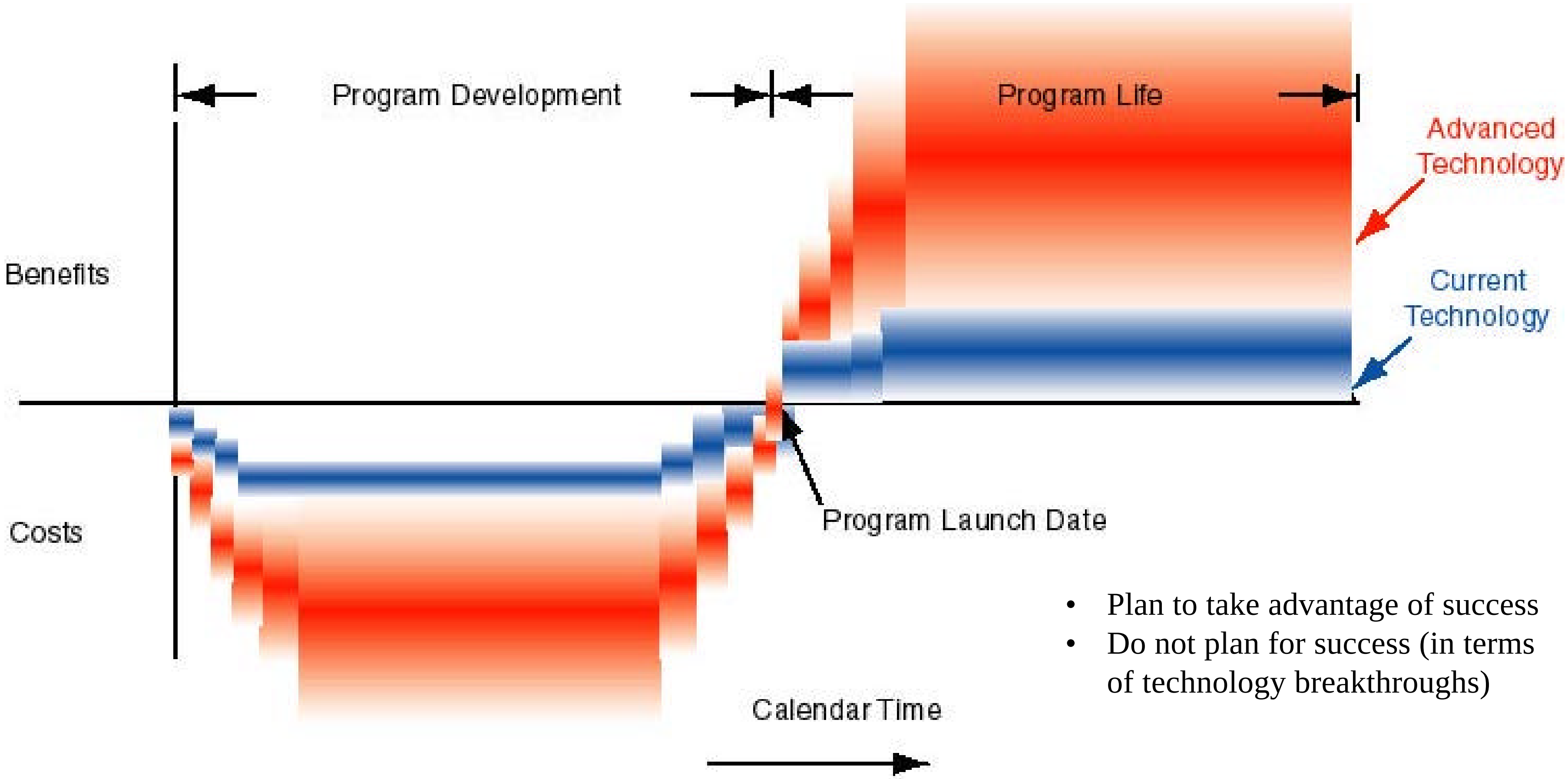
Risk-Based Design Philosophy

- Identify the benefits to NASA Human and Robotic Exploration Goals and Objectives by incorporating revolutionary technologies
- Benefits are derived at a top-level from NASA Vision statement
- Benefits are characterized for the RASC 1 activity in terms of:
  - Probability of Crew Safety
  - Probability of Mission Success
  - Probability of Technical Development Success [TRL]
- Risk is defined as a combination of Probability, Consequence, and Perceived Utility
  - Risk Averse Utility function => Path to O2
  - Risk Taker Utility function => Path to O1



Outcome distributions O1 and O2 are typical of the choice between a new technology and a proven technology

Benefit Return of Technology Investment



- Plan to take advantage of success
- Do not plan for success (in terms of technology breakthroughs)

Typical Investment Cost Benefit Streams (Undiscounted)
for
Current and Advanced Technology

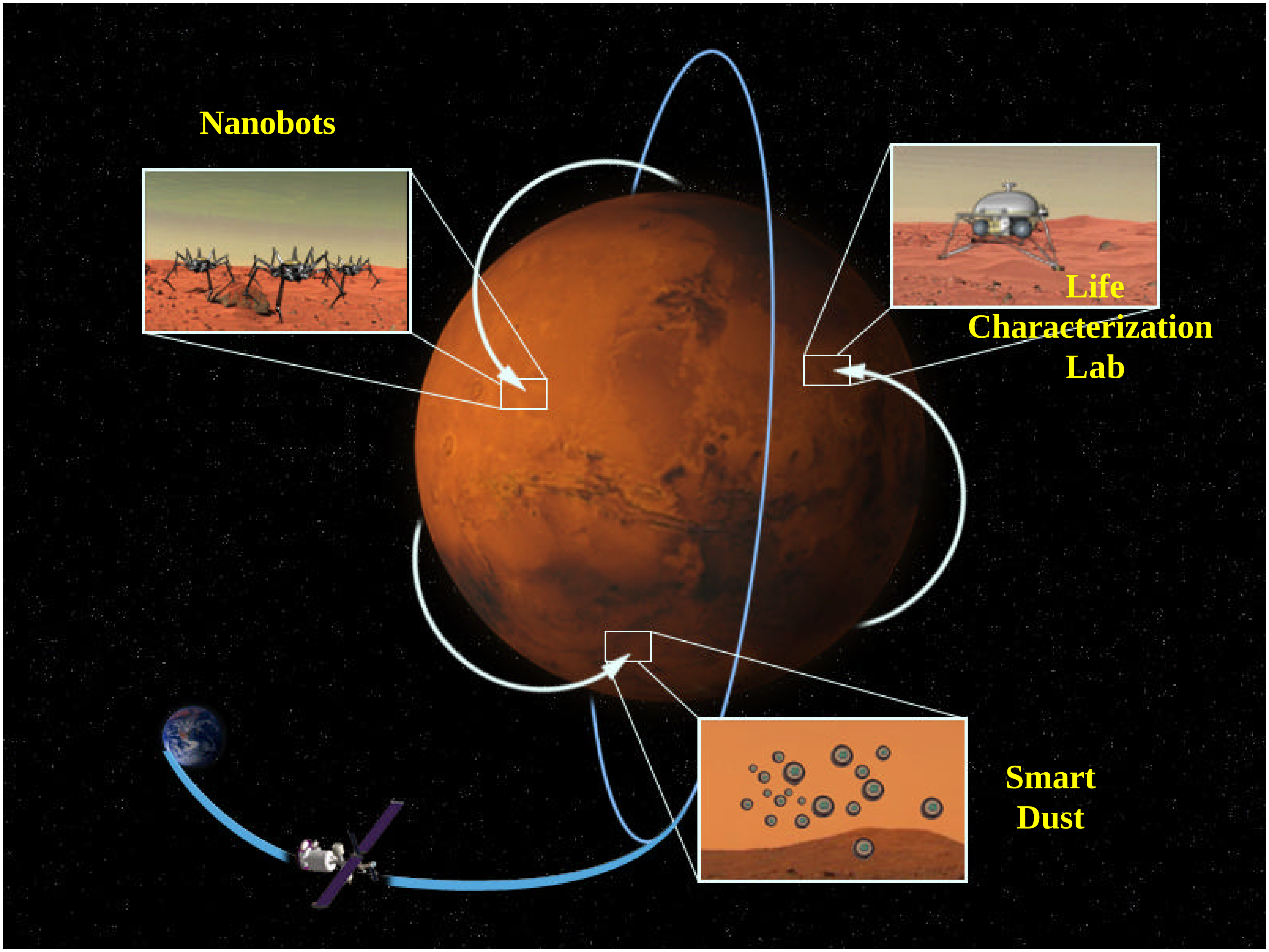
Note Advanced Technology "Promises" higher return for greater investment but the return has greater uncertainty

Mars Human Mission Options

- Allows for the evaluation of different technologies at an architectural, concept, and system level for both:
  - Human Missions
  - Robotic Missions
- Supports the assessment of a re-usable nuclear based transportation architecture including use of Mars orbit NEP tanker

Option	Assembly Location	Departure Location	Mars Orbital Location	Arrival Location	Notes
1	LEO	LEO	500 km circular	EM L1	LEO assembly benefits Re-use compatible w/OASIS
2	EM L1	EM L1	500 km circular	EM L1	Fully compatible w/OASIS infrastructure
3	LEO	LEO	500 km circular	LEO	Simplest transportation arch. w/associated risk
4	LEO	LEO	24hr elliptical 250km x 33730 km	EM L1	
5	LEO	LEO	Phobos [6000km] circular	EM L1	Permanent Mars orbit space station, potential ISRU

Mars Robotic Mission Architecture



Bimodal Nuclear Electric Propulsion

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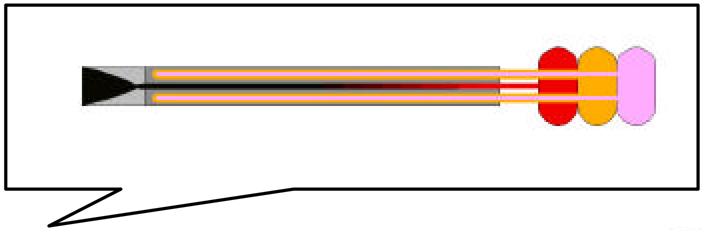
Hybrid Propulsion

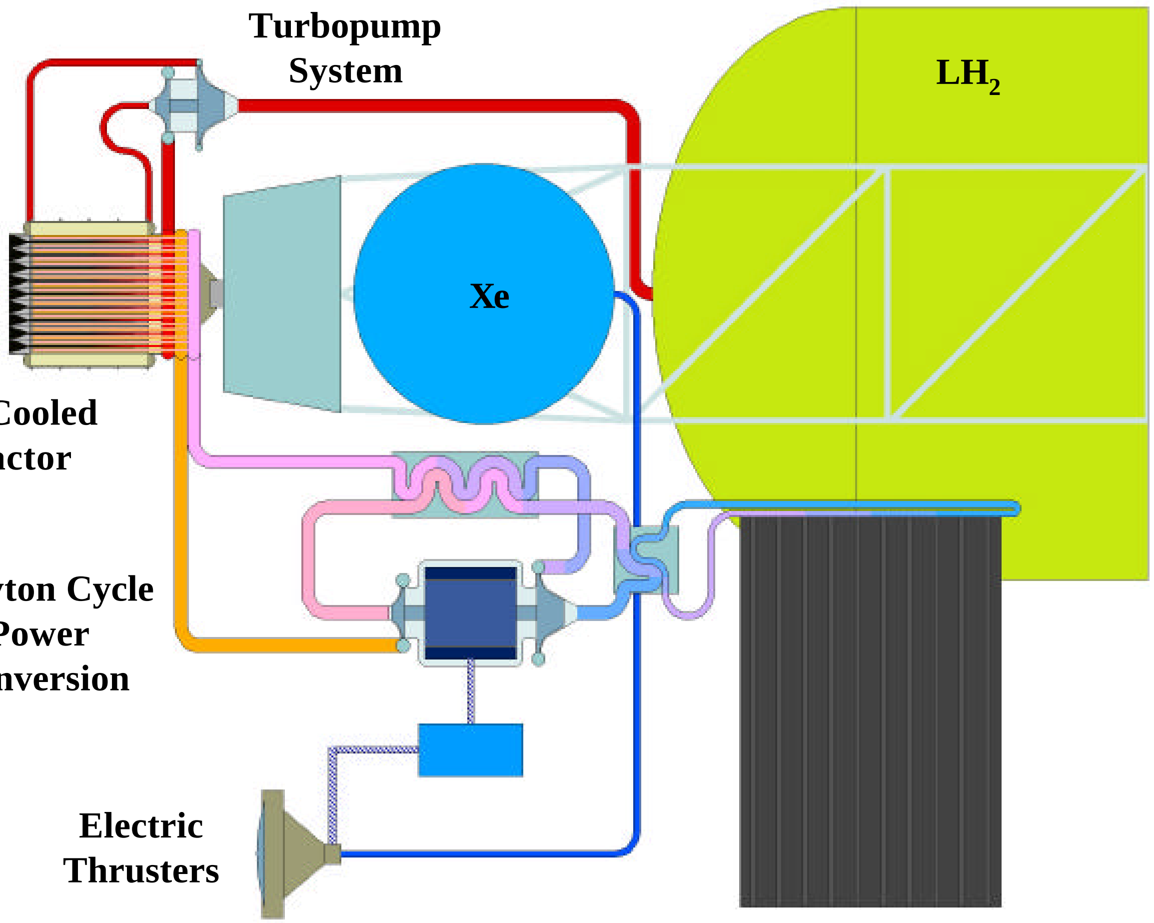
- **Hybrid propulsion is the combination of two discrete propulsion systems with fundamentally different characteristics**
  - **High Thrust**
    - Low Specific Impulse (Isp) generally less than 1000 sec
    - High acceleration generally above .01g
    - Provides “quick” velocity changes within strong gravity fields: “impulsive”
  - **Low Thrust**
    - High Specific Impulse generally 1000 sec and can be greater than 10000 sec
    - Low acceleration generally below .001g
    - Provides efficient velocity changes over time
- **A single mission can benefit from the use of both types of propulsion if each is used where it is most efficient**
- **Mission performance benefits can be offset by the dry mass of two propulsion systems and operational complexity**
- **High temperature gas cooled reactor fuels technology enables potential integration of High Thrust Thermal with Low Thrust Electric Propulsion technologies with minimal increase is system dry mass**

Bimodal Nuclear Electric Propulsion

A Fully Integrated Bimodal Propulsion and Power System

- During high thrust mode, LH2 propellant is thermally accelerated through the reactor, which produces thermal megawatts at >2000 °K
- During power generation, the gas cooled reactor produces thermal kilowatts at ~1500°K
- Dynamic power conversion generates electrical power to for Electric Propulsion and other vehicle systems



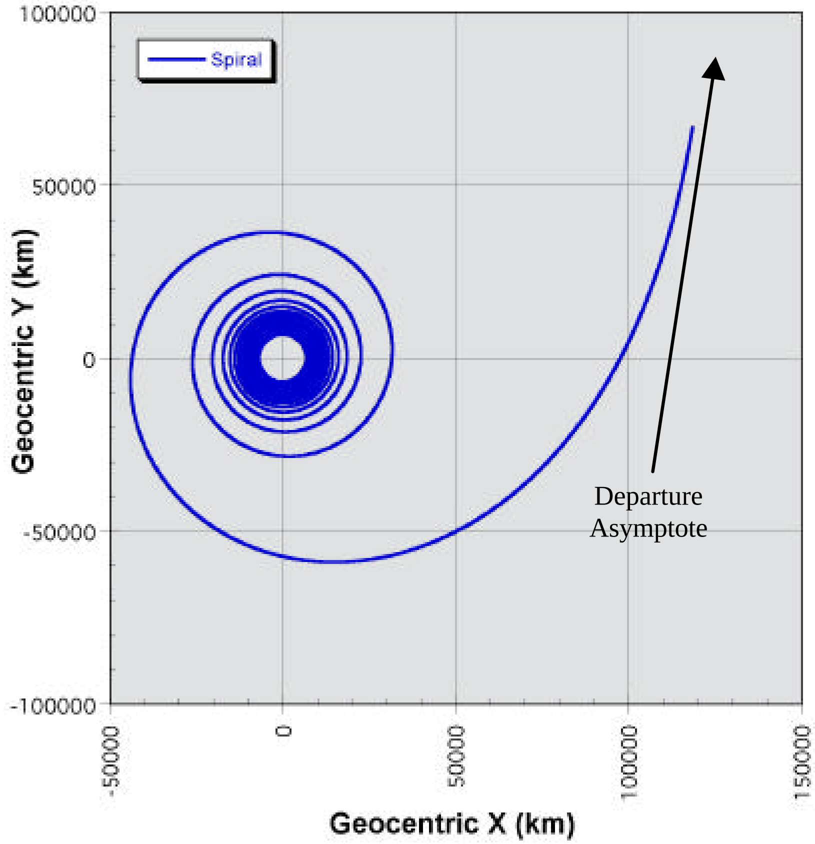


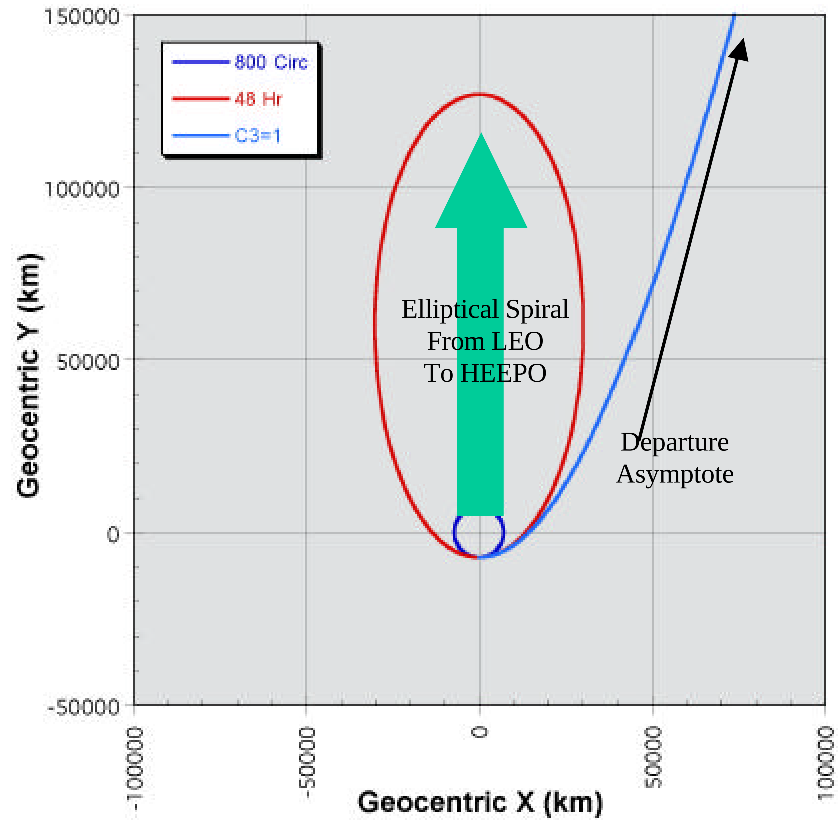
Bimodal Nuclear Electric Propulsion Benefits

- **Enhanced mission performance with smaller, nearer-term technology subsystems than NEP alone**
  - Enables very demanding missions such as Interstellar Probe
- **New mission classes enabled**
  - High thrust mode can be used for descent/ascent
  - BNEP used for descent can provide surface power for ISRU
  - ISRU propellant can be utilized for LOX augmentation and sample return missions
  - Can be used as a Nuclear Ramjet for Jupiter atmospheric flyer
- **Evolvable technology to larger sizes required to support Human Missions**
  - BNEP reduces the step size from science class systems to human class systems
- **One fuels development program (eg. CERMET) supports NTR, BNTR, NEP, combined BNTR/EP, and surface power systems**
  - CERMET Fuel has synergy with DOE/Naval Reactors Division, and industry (BWX Technologies) support base
- **Wide latitude of mission performance reduces program risk**
  - Mission architecture is forgiving to system technology & performance

Hybrid Propulsion Trajectories

Comparison of Technologies Effect on Geocentric Trajectories





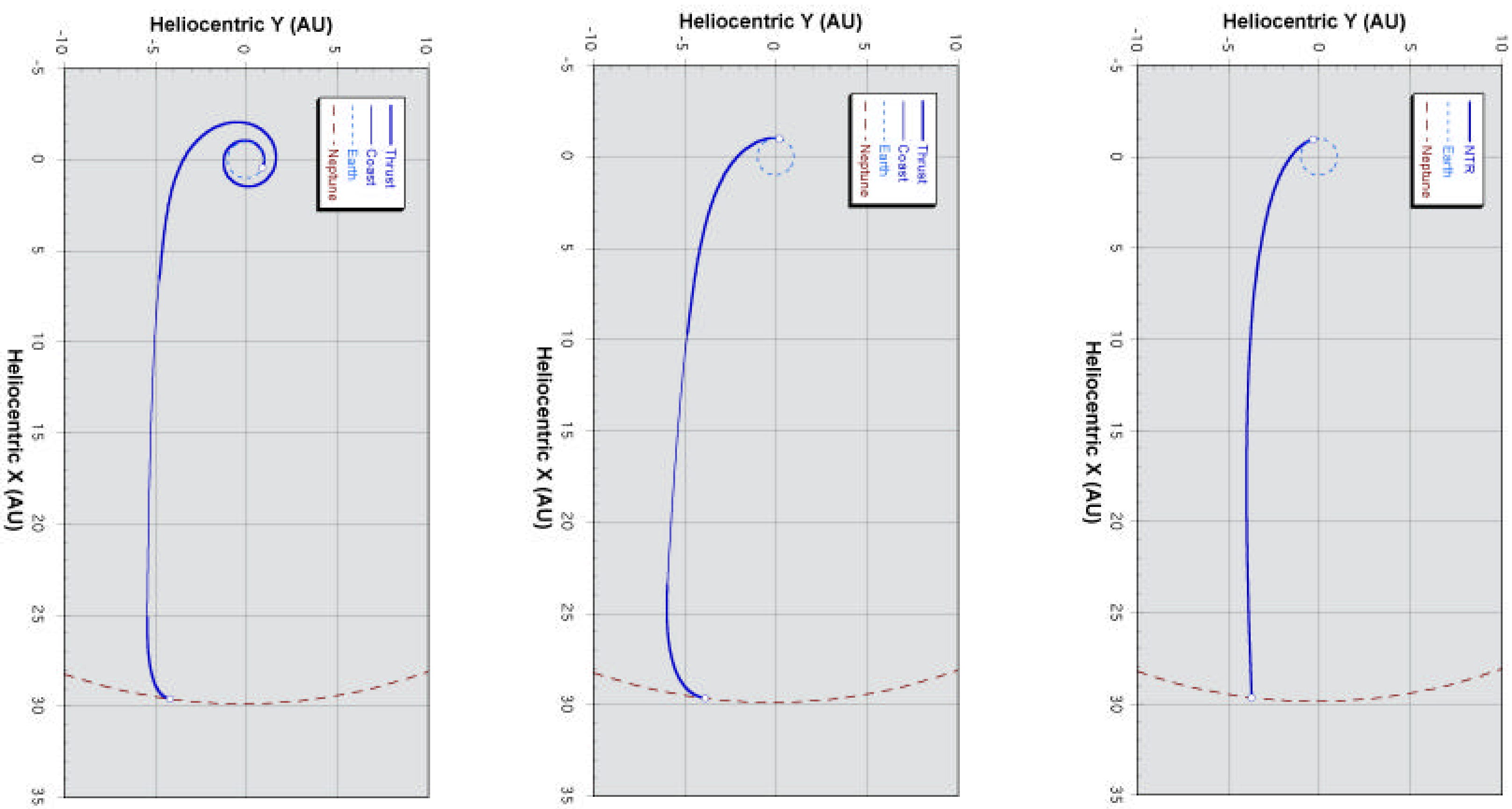
NEP
Circular Escape Spiral
Zero Energy Departure
Significant Departure Time

BNEP
Elliptical Spiral to HEEPO
Significant Departure Time, but supports reduced IMLEO
OR
High Energy Departure
Minimal Departure Time

NTP
High Energy Departure
Minimal Departure Time

Hybrid Propulsion Trajectories

Comparison of Technologies Effect on Interplanetary Trajectories



NEP
Zero Energy Departure
and Arrival

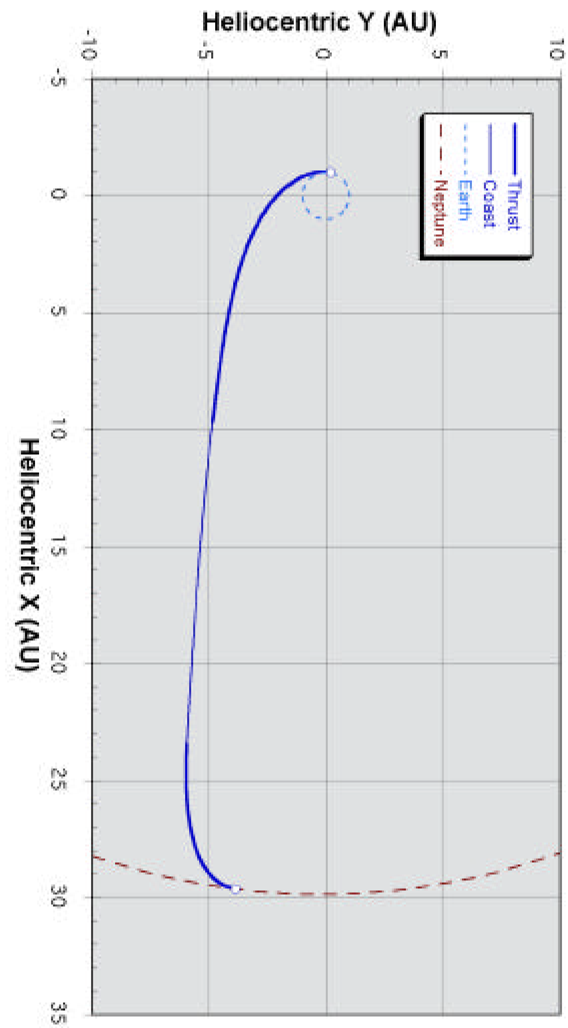
BNEP
(Less) Positive Energy Departure
Zero Energy Arrival

NTP
Positive Energy Departure
and Arrival

Neptune Orbiter Scientific Probe

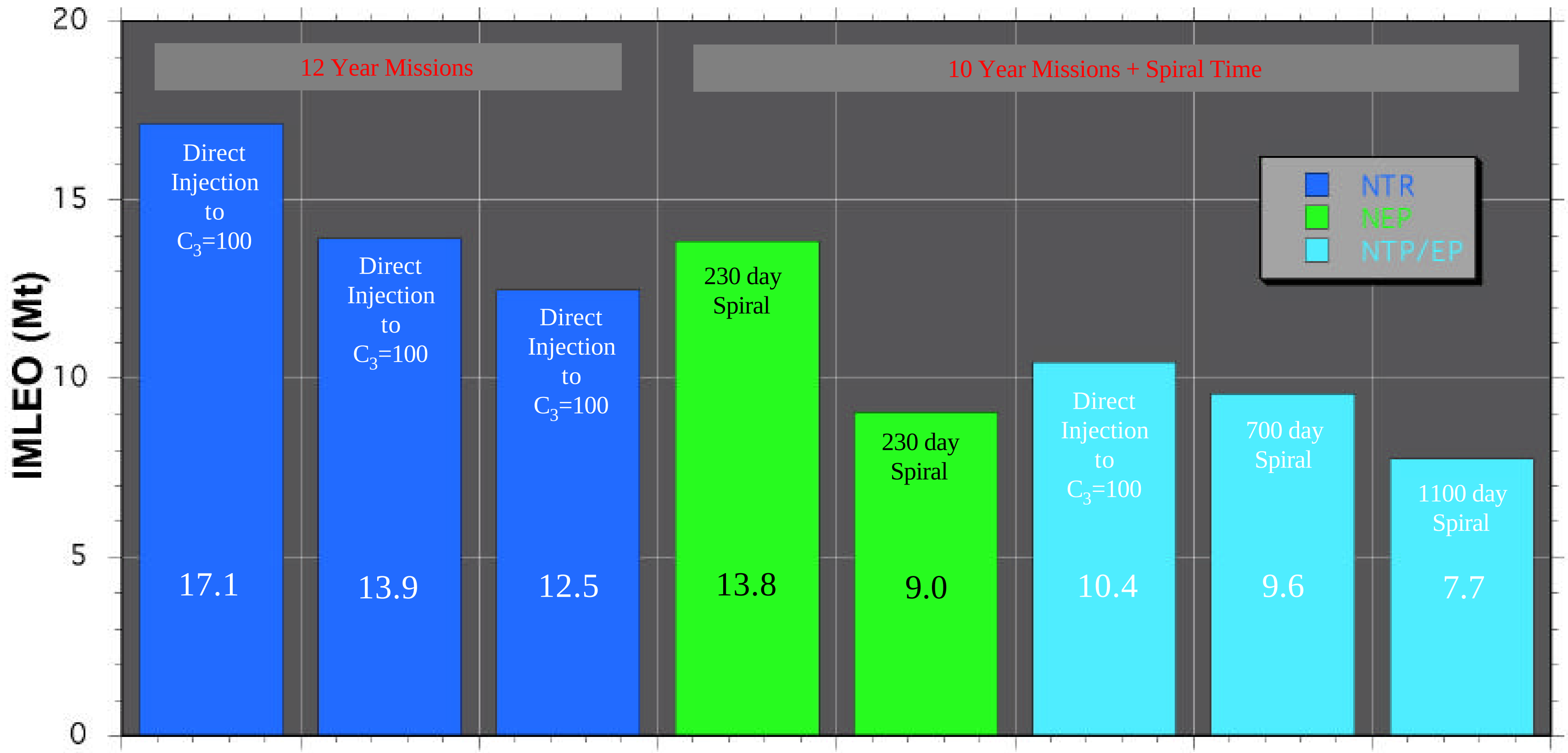
- **NASA Office of Space Science Potential Mission**
- **2010 Departure with10-12 Year Transit**
- **500 kg Science Payload**
- **NEP:**
  - **Spiral Earth Escape from LEO (407 km circular)**
  - **EP Rendezvous and Spiral Neptune Capture**
- **NTP**
  - **NTR Earth Escape from LEO to C3=160 km^2/sec^2**
  - **Propulsive Neptune Capture**
- **BNEP Option 1**
  - **NTR Earth Escape from LEO to C3=100 km^2/sec^2**
  - **EP Interplanetary**
  - **NTR Propulsive Neptune Capture**
  - **EP orbit phasing with Trition**
- **BNEP Option 2**
  - **EP LEO-HEEPO Spiral prior to Trans-Neptune Injection**
  - **Jettison LH2 Tank after TNI**
  - **EP Rendezvous and Spiral Neptune Capture**

High Energy Outer Planet Mission



Nuclear Technologies Performance Comparison

Neptune Orbiter Scientific Probe

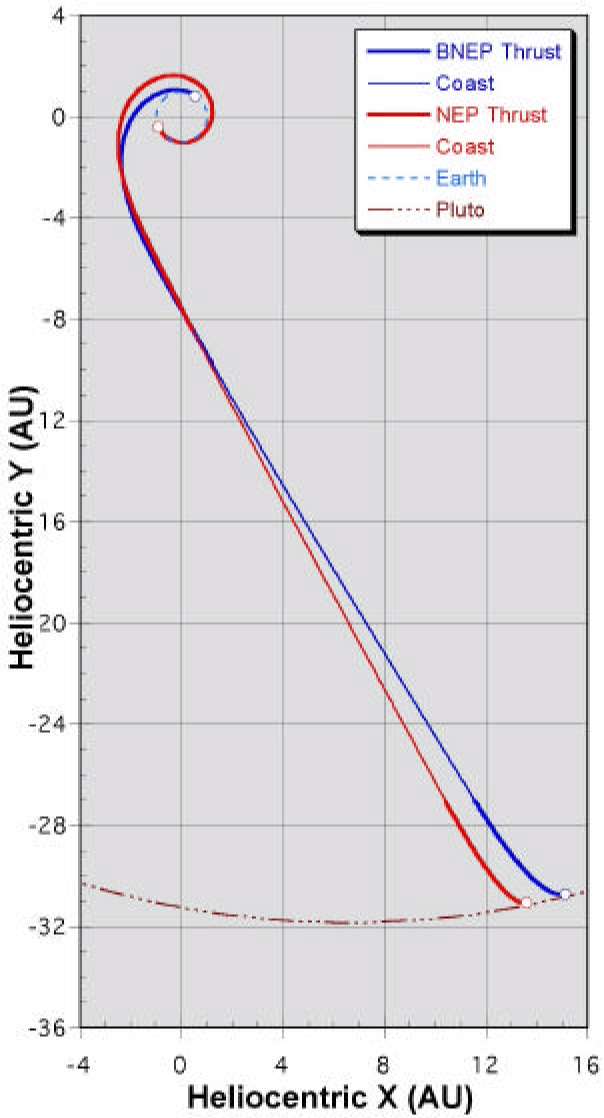


BNTR	BNTR	BNTR	NEP	NEP	BNTR/EP	BNTR/EP	BNTR/EP
NERVA Technology	**Composite Fuel Technology**	**Cermet Fuel Technology**	**“Near-Term” Technology**	**“Mid-Term” Technology**	**“Near-Term” Technology**	**“Near-Term” Technology**	**“Near-Term” Technology**
Isp 880 sec	Isp 915 sec	Isp 940 sec	Specific Mass 37 kg/kWe	Specific Mass 31 kg/kWe	Specific Mass 96 kg/kWe	Specific Mass 85 kg/kWe	Specific Mass 91 kg/kWe
			87 kWe	57 kWe	18 kWe	21 kWe	18 kWe
			Isp 6800	Isp 6800	Isp 7500	Isp 7500/3000	Isp 7500/5500
					NTR Isp 940	NTR Isp 940	NTR Isp 940

Detailed Mission Study: Pluto Orbiter Mission

- **NASA Office of Space Science potential mission to study condensing atmosphere in 2020-2023**
- **2011 Departure, 10 years to Pluto**
- **500 kg Science Package**
- **NEP:**
  - **Spiral Earth Escape from SHO (2500 km circular)**
  - **EP Interplanetary**
  - **EP Rendezvous, and Spiral Pluto Capture**
  - **"SOA" Brayton NEP System**
    - 1150°K TIT, 6kg/m^2 Rad, 2000V PMAD
    - 5 kg/kW_e EP Subsystem, 10% Tankage
- **BNEP:**
  - **High Thrust Mode Escape from SHO to C3=29 km^2/sec^2**
  - **EP Interplanetary**
  - **EP Rendezvous and Spiral Pluto Capture**
  - **"SOA" Brayton NEP System with ESCORT thrust mode components**
    - +10% reactor mass, 165 kg nozzles, pumps,etc.
    - Al LH_2 tanks jettisoned after escape

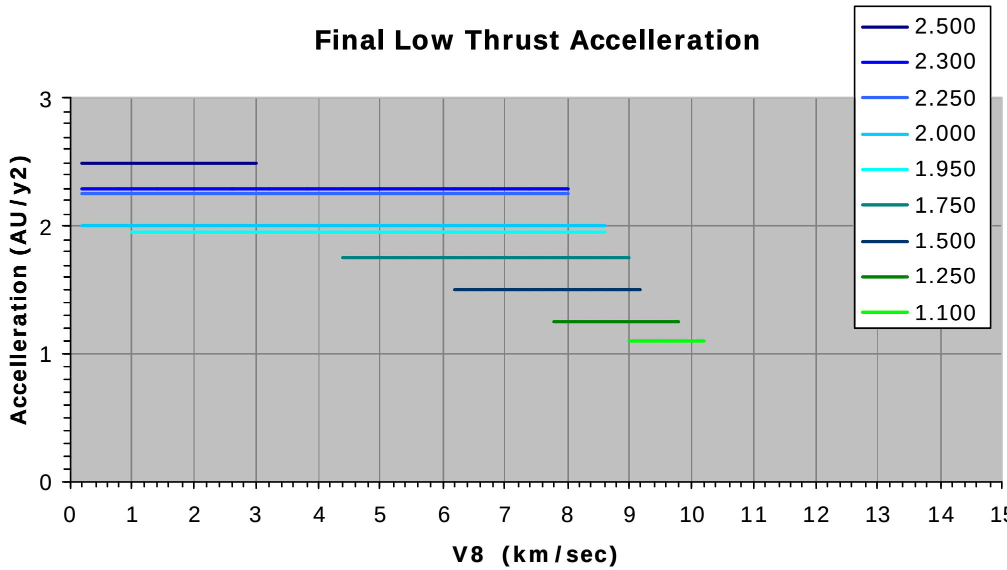
High Energy Outer Planet Mission

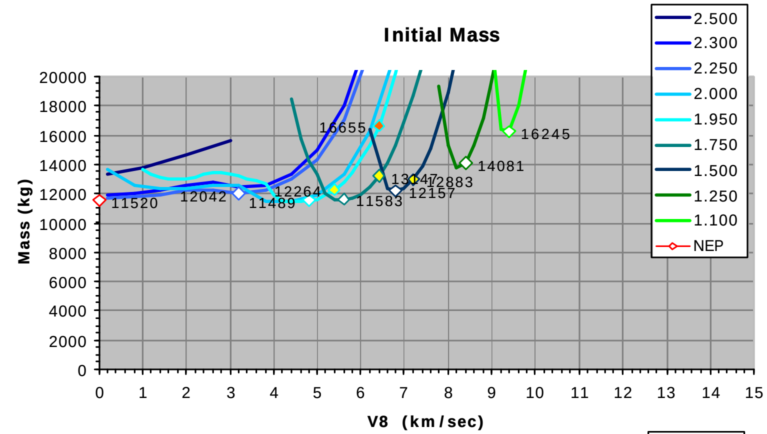


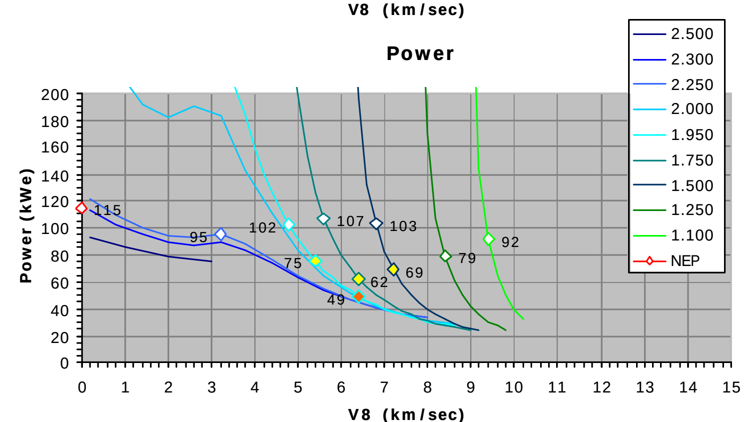
BNEP Mission Performance Latitude

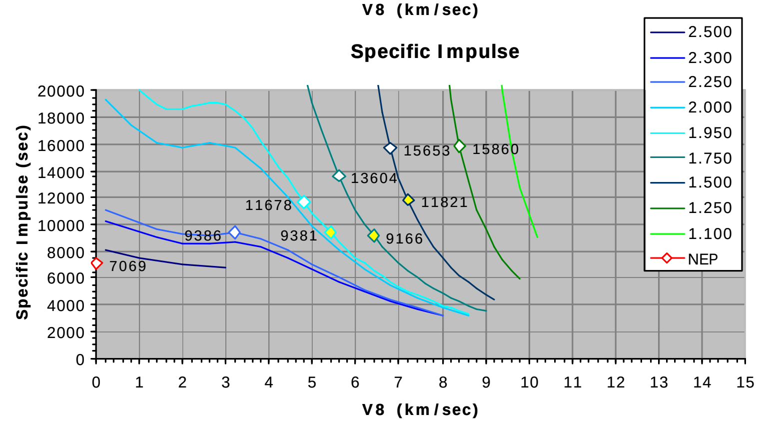
10 year Pluto Orbiter Mission

- BNEP provides a wide latitude of possible missions with a given system technology
  - Reduces program risk
- BNEP requires less power than NEP
  - Significant reductions in power are possible by using more LH_2



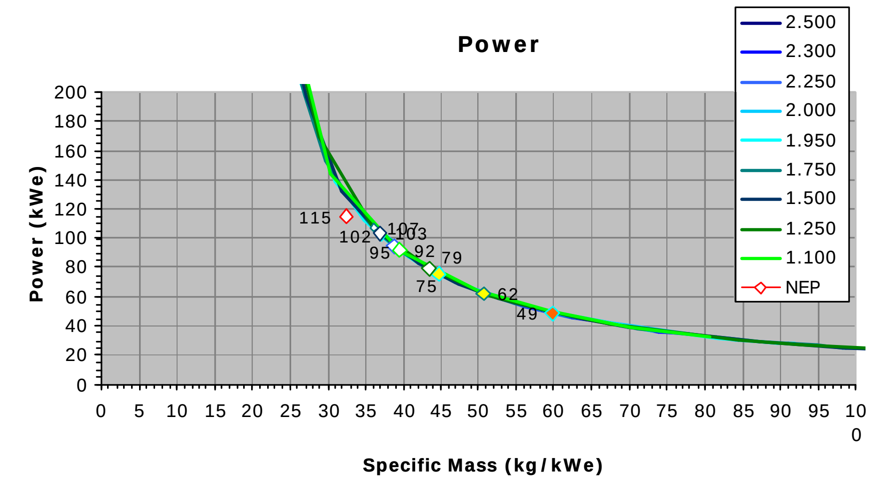


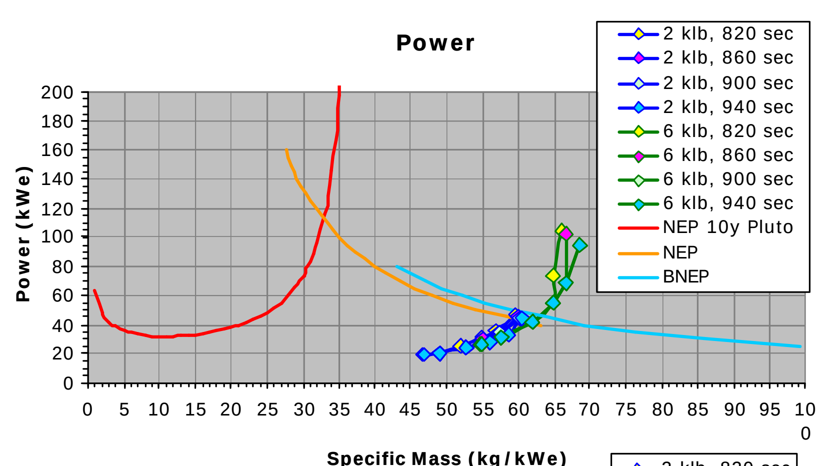


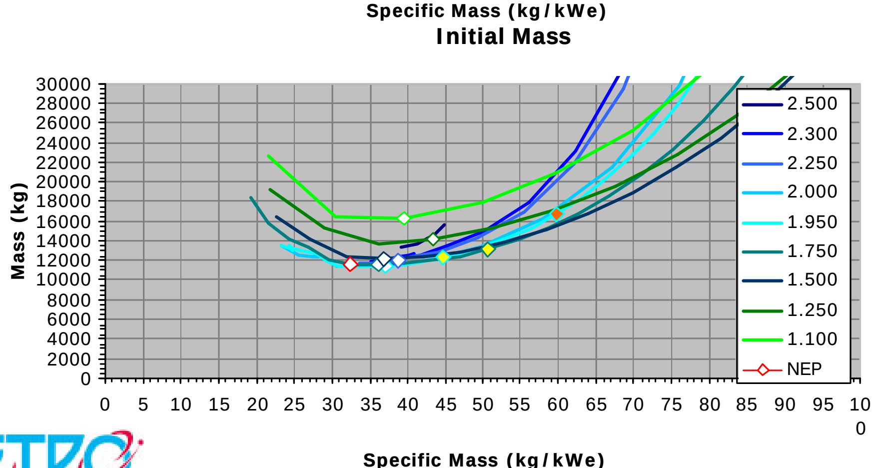


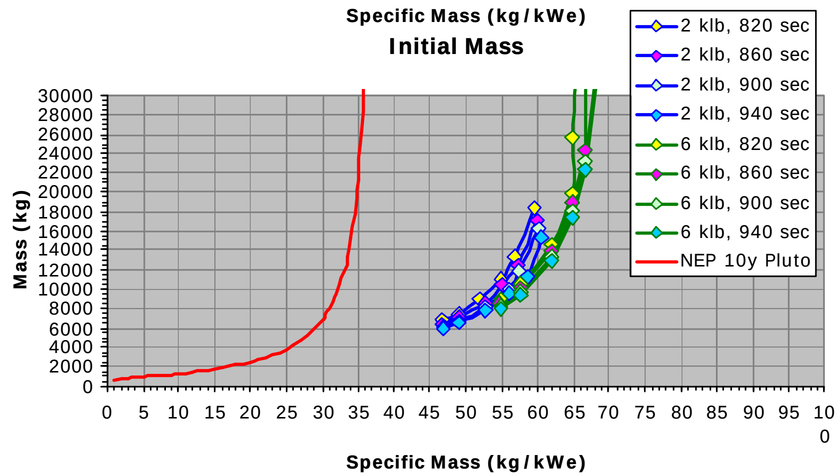
BNEP System Performance Latitude for a 10 Year Pluto Orbiter Mission

- **Bimodal NEP provides a more robust capability to meet future deep space mission requirements than a straight NEP system**
  - NEP requires a Specific Mass of < 35 kg/kW$_e$ and power 115 kW$_e$
  - BNEP supports a Specific Mass up to ~60 kg/kW$_e$ and power levels as low as 20 kW$_e$



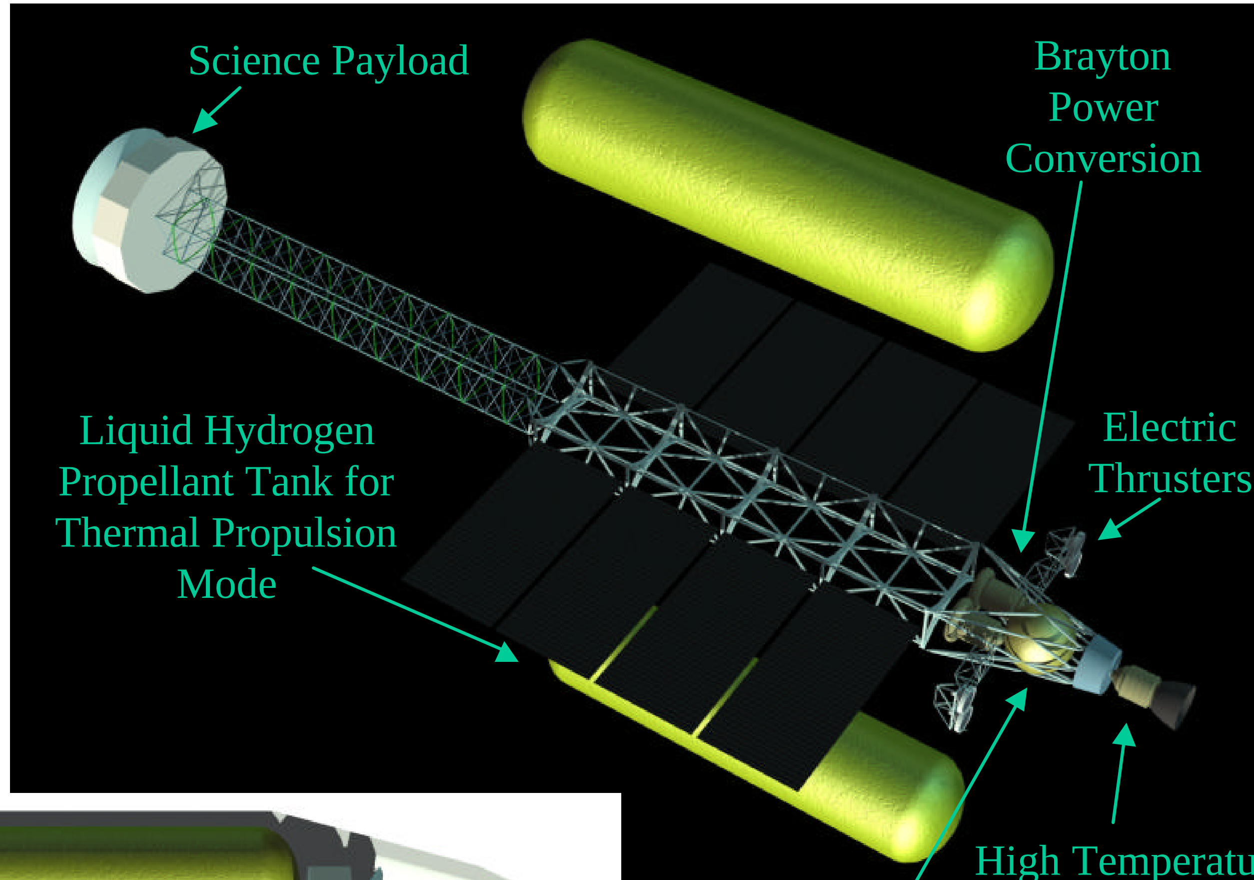




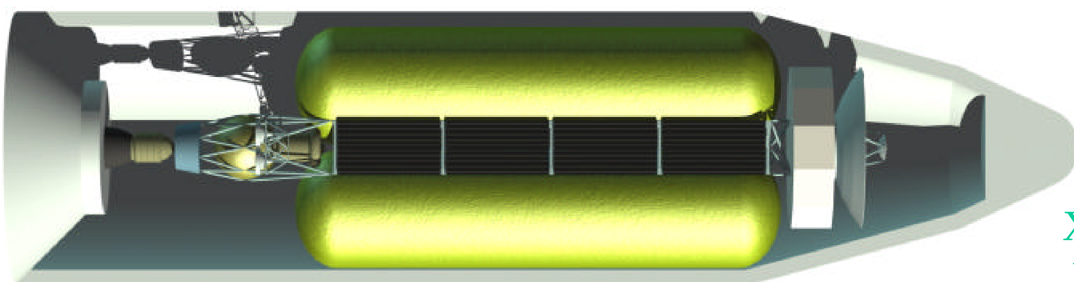


BNEP Concept: Scientific Probe To Pluto

- **75 kWe EP**
  - **9400 sec**
- **3 klbf NTR**
  - **900 sec**
- **12.2 Mg Launch Mass**
  - **5 Mg LH_2**
  - **2.2 Mg Xe**



Delta IV-H Launch Package



Nuclear Propulsion for Human Exploration Missions

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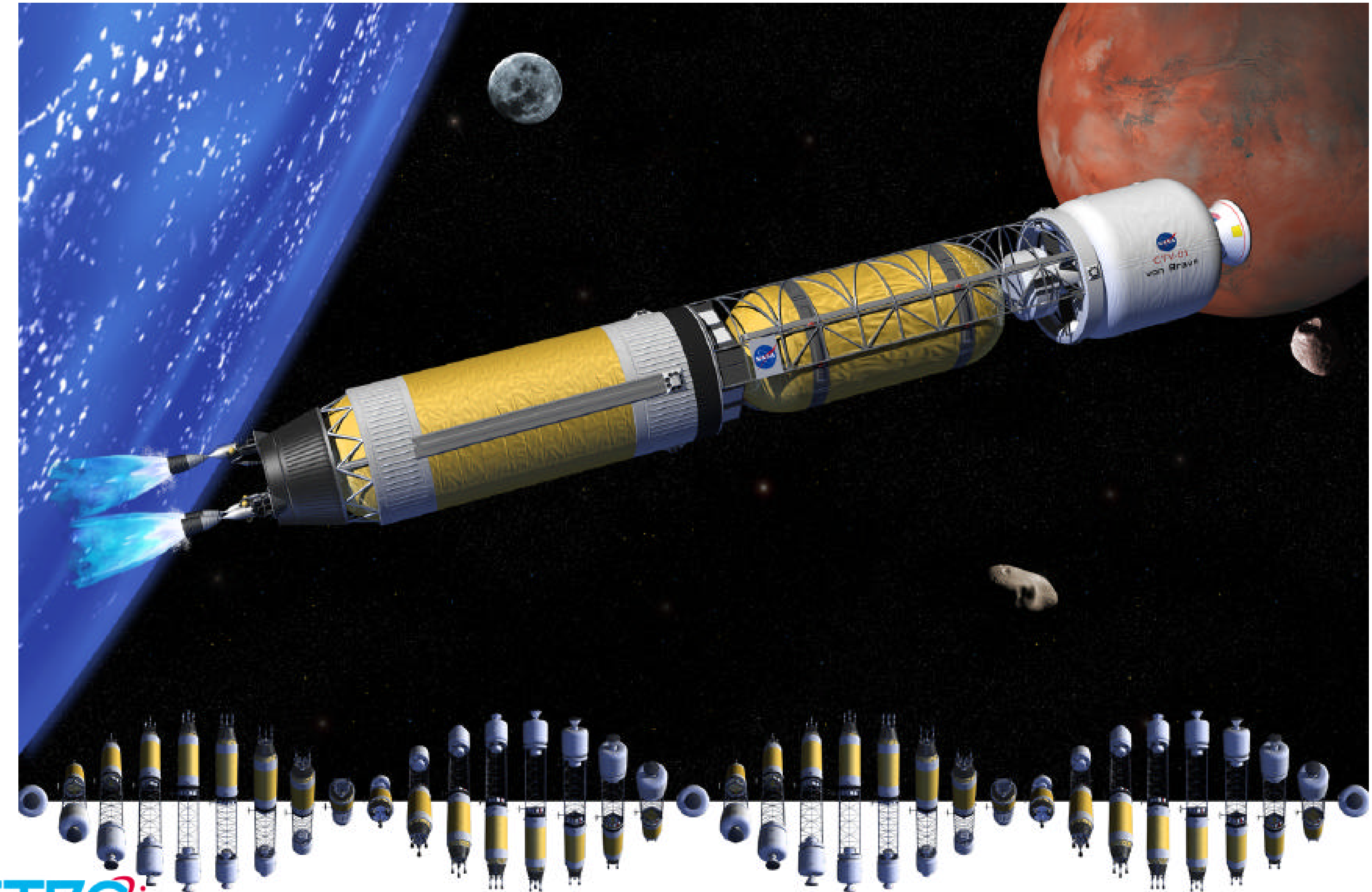
Space Transportation Project Office
Glenn Research Center

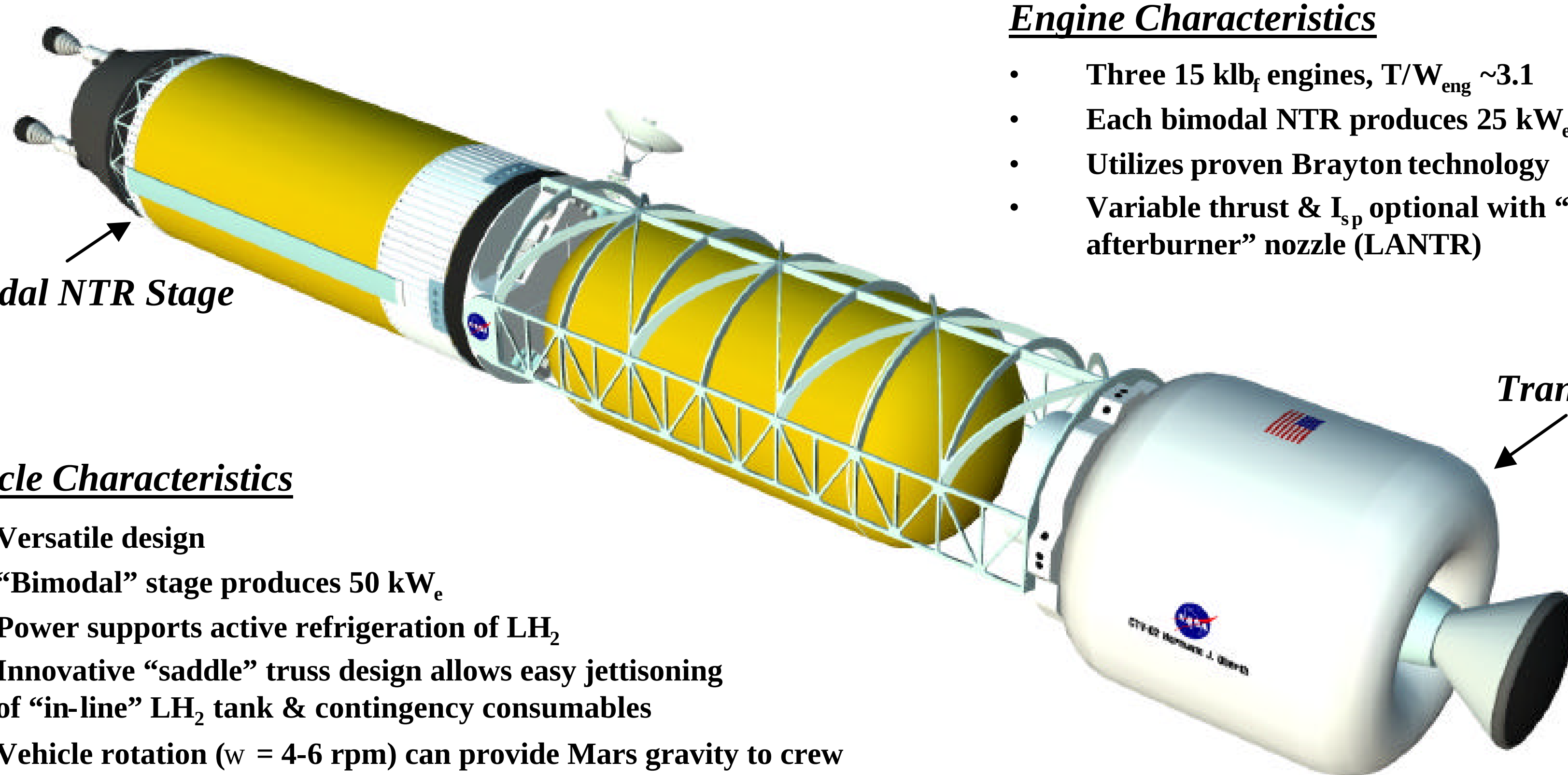
Power & Propulsion Office

Artificial Gravity "Bimodal" NTR Crew Transfer Vehicle (CTV) for Mars and NEA Missions



Modular "Bimodal" NTR Transfer Vehicle Design for Mars Cargo and Piloted Missions

Bimodal NTR: High thrust, high I_{sp} propulsion system utilizing fissioning U^{235} produces thermal energy for propellant heating and electric power generation enhancing vehicle capability



Bimodal NTR Stage

TransHab

Engine Characteristics

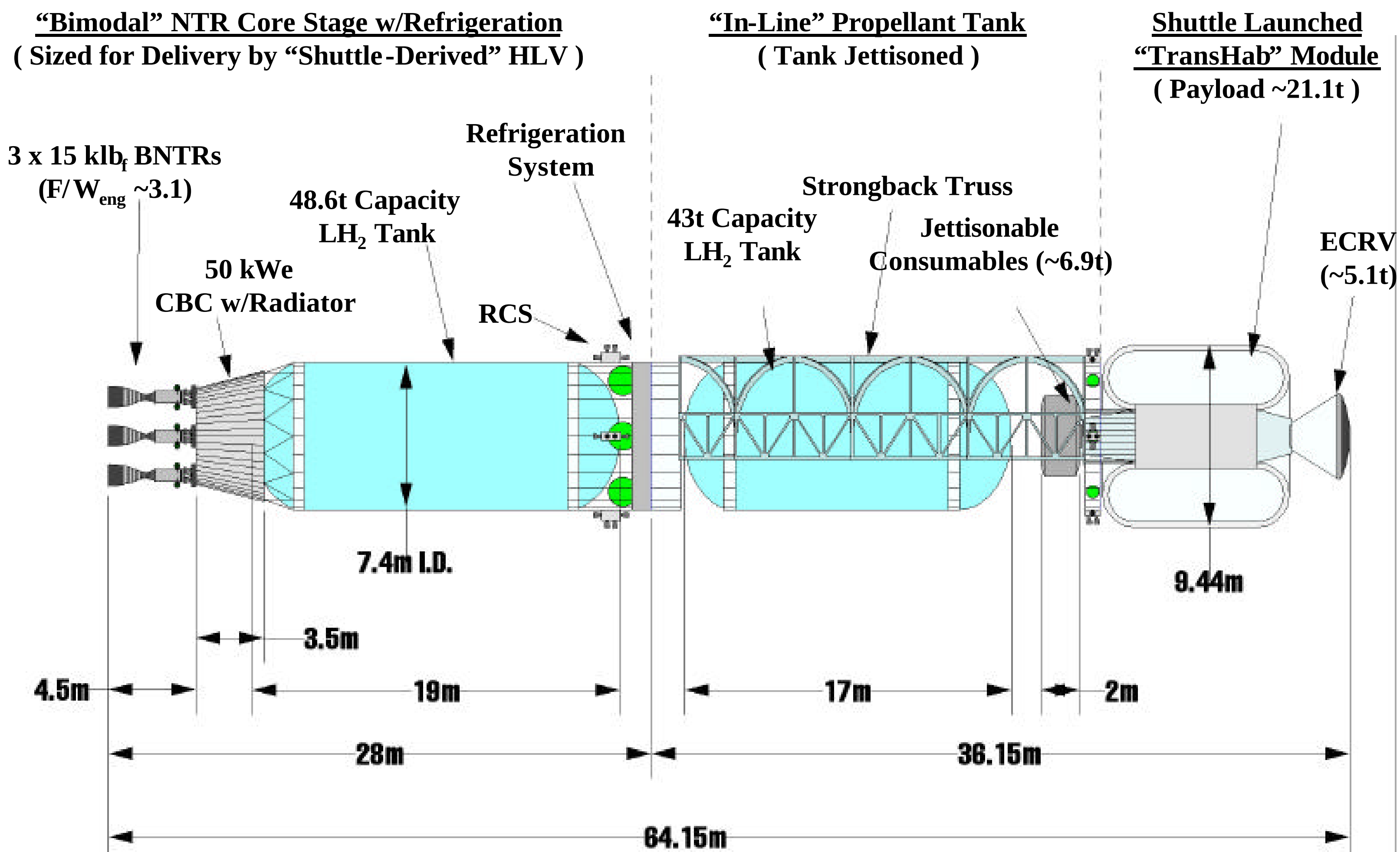
- **Three 15 klb_f engines, T/W_{eng} ~3.1**
- **Each bimodal NTR produces 25 kW_e**
- **Utilizes proven Brayton technology**
- **Variable thrust & I_{sp} optional with "LOX-afterburner" nozzle (LANTR)**

Vehicle Characteristics

- **Versatile design**
- **"Bimodal" stage produces 50 kW_e**
- **Power supports active refrigeration of LH_2**
- **Innovative "saddle" truss design allows easy jettisoning of "in-line" LH_2 tank & contingency consumables**
- **Vehicle rotation (w = 4-6 rpm) can provide Mars gravity to crew outbound and near Earth gravity inbound (available option)**
- **Propulsive Mars capture and departure on piloted mission**
- **Fewest mission elements, simple space ops & reduced crew risk**
- **Bimodal NTR vehicles easily adapted to Moon & NEA missions**

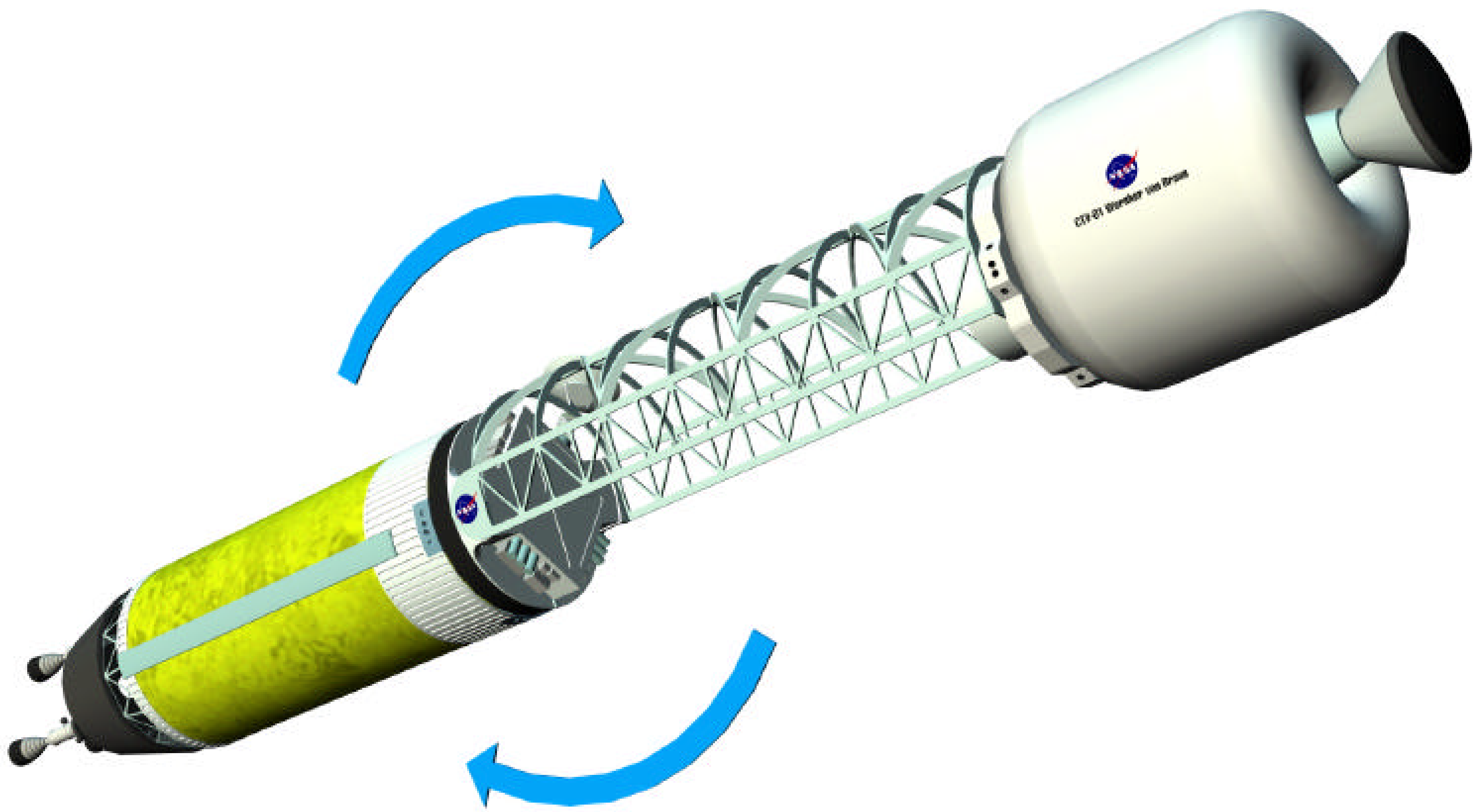
Piloted Transfer Vehicle

“Bimodal” NTR Crew Transfer Vehicle (CTV)



IMLEO: ~166.4 t

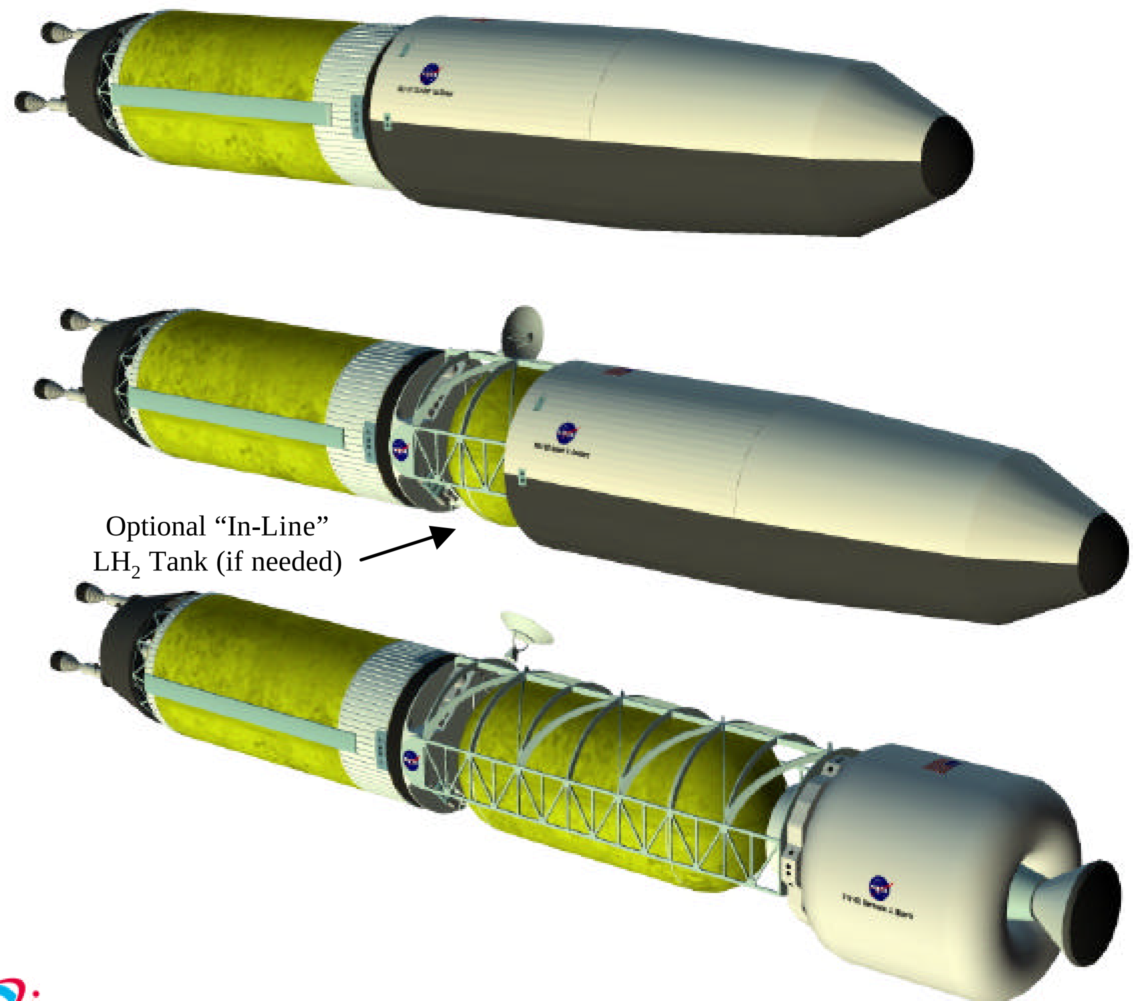
"Bimodal" NTR Crew Transfer Vehicle (CTV) in Artificial Gravity Mode



Ref: Borowski et al., AIAA-99-2545

"Bimodal" NTR Cargo & Crew Transfer Vehicles for 1999 Mars Design Reference Point 4.0

6 - "80 t" SDHLVs plus Shuttle for Crew & TransHab Delivery

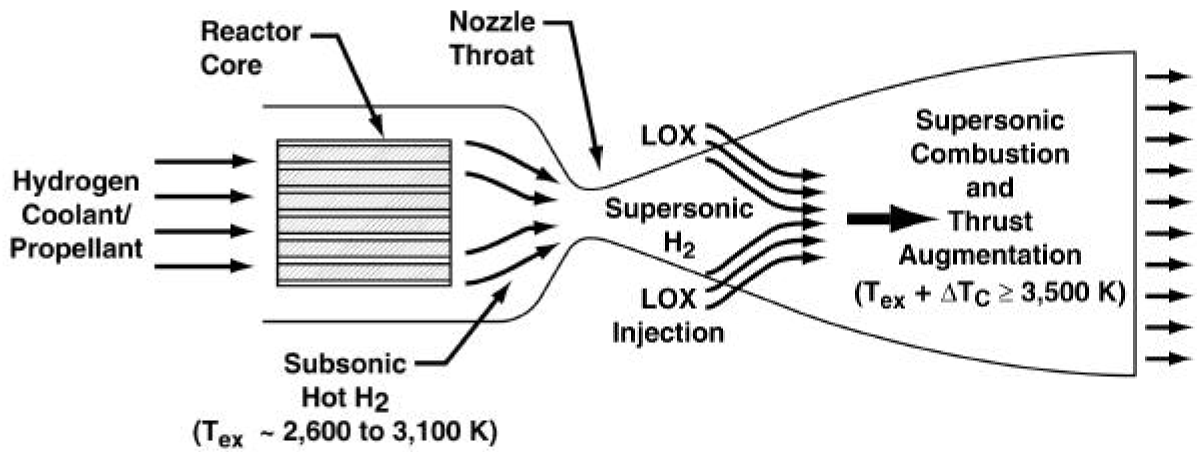


2011 Cargo Mission 1
Habitat Lander
IMLEO= 131.0 t

2011 Cargo Mission 2
Cargo Lander
IMLEO= 133.7 t

2014 Piloted Mission
Artificial Gravity
Crew Transfer Vehicle
IMLEO= 166.4 t

"LOX-Augmented" NTR (LANTR) Concept
--Operational Features and Characteristics--

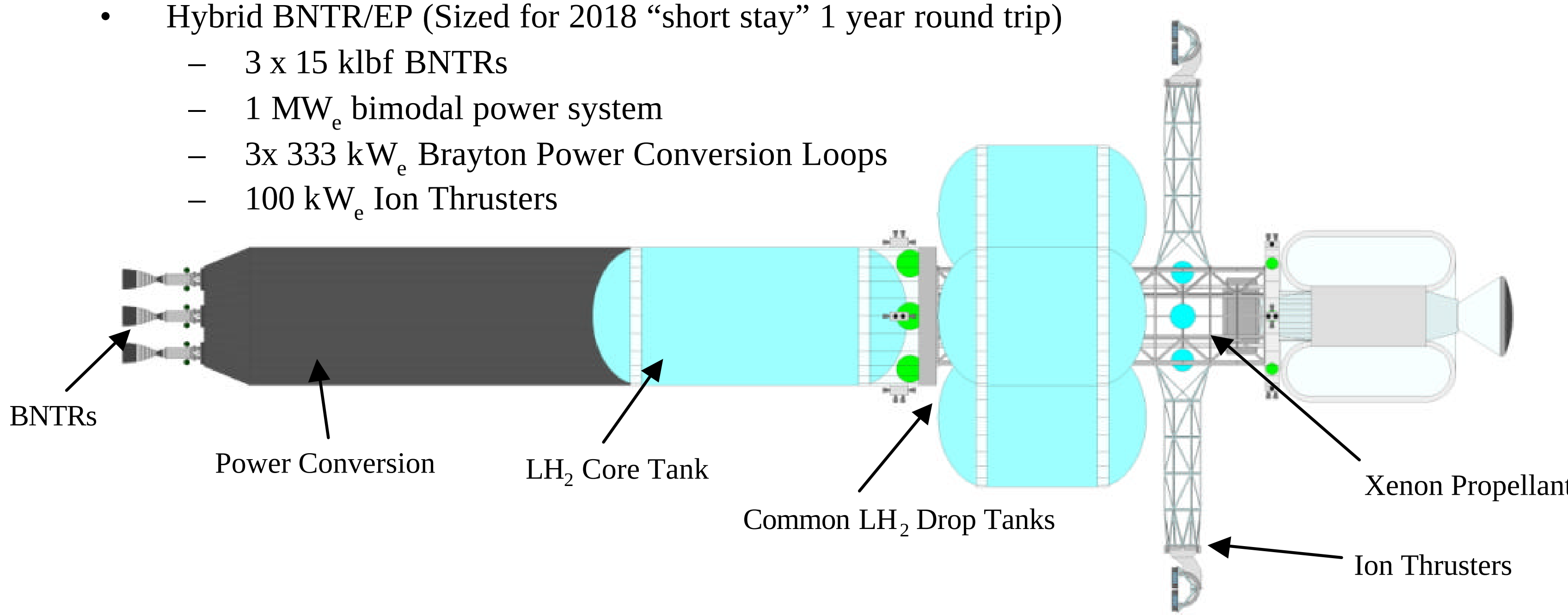


	I_{sp} (sec)				
Life (hrs) T_{ex} (°K)	5 2,900	10 2,800	35 2,600	Tankage Fraction (%)	T/W_{eng} Ratio
O/H MR = 0.0	941	925	891	14.0	3.0*
1.0	772	762	741	7.4	4.8
3.0	647	642	631	4.1	8.2
5.0	576	573	566	3.0	11.0
7.0	514	512	508	2.5	13.1

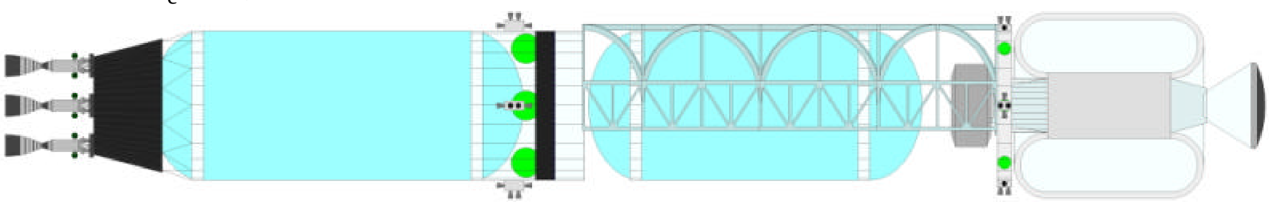
*For 15 klb_f LANTR with chamber pressure = 2,000 psia and ε = 500 to 1

BNTR Vehicles for Human Mars Missions

- Hybrid BNTR/EP (Sized for 2018 “short stay” 1 year round trip)
  - 3 x 15 klbf BNTRs
  - 1 MW_e bimodal power system
  - 3x 333 kW_e Brayton Power Conversion Loops
  - 100 kW_e Ion Thrusters

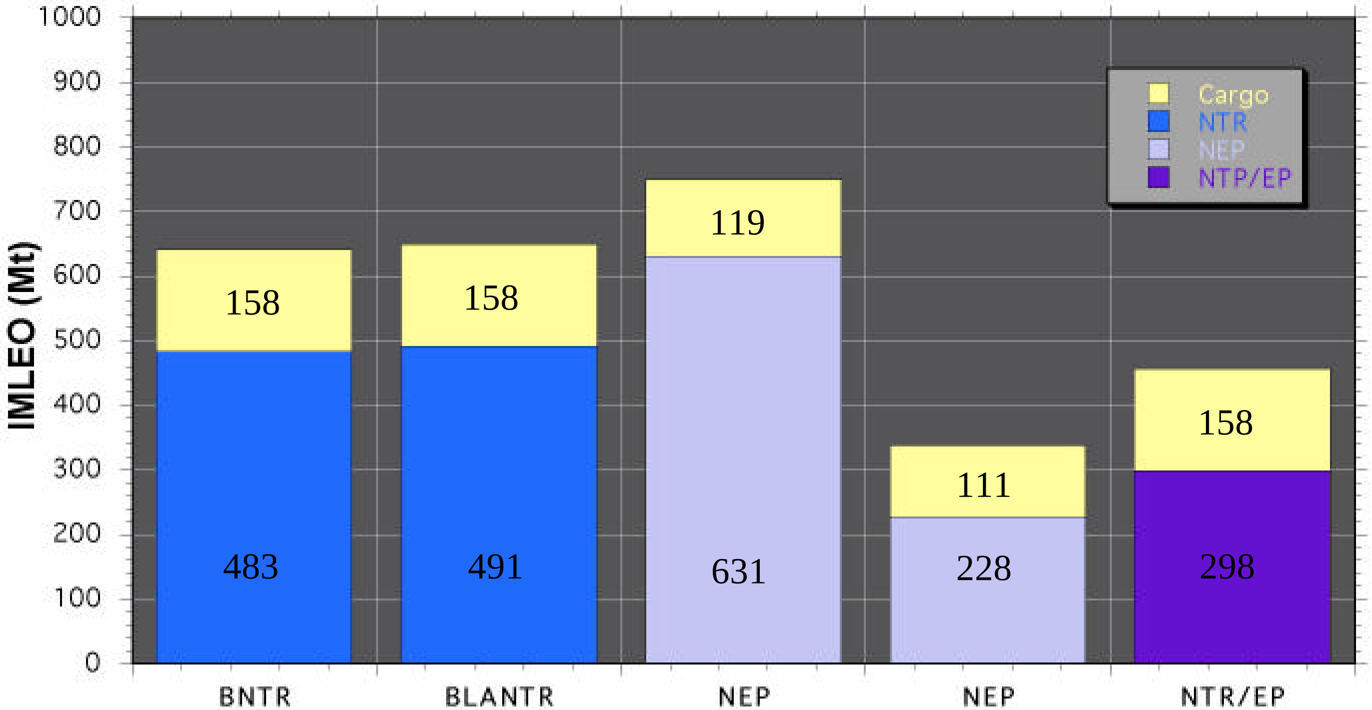


- BNTR (Note: This vehicle sized for lower energy, long stay mission)
  - 3 x 15 kbf BNTRs
  - 50 kW_e bimodal power system
  - 3+1 25 kW_e Brayton Power Conversion Loops



Performance Comparison: Human Mars Mission

2018 Mars Opposition 1 Year Round Trip
(Pre-deploy Cargo / Crew travels to and from Mars in same vehicle)



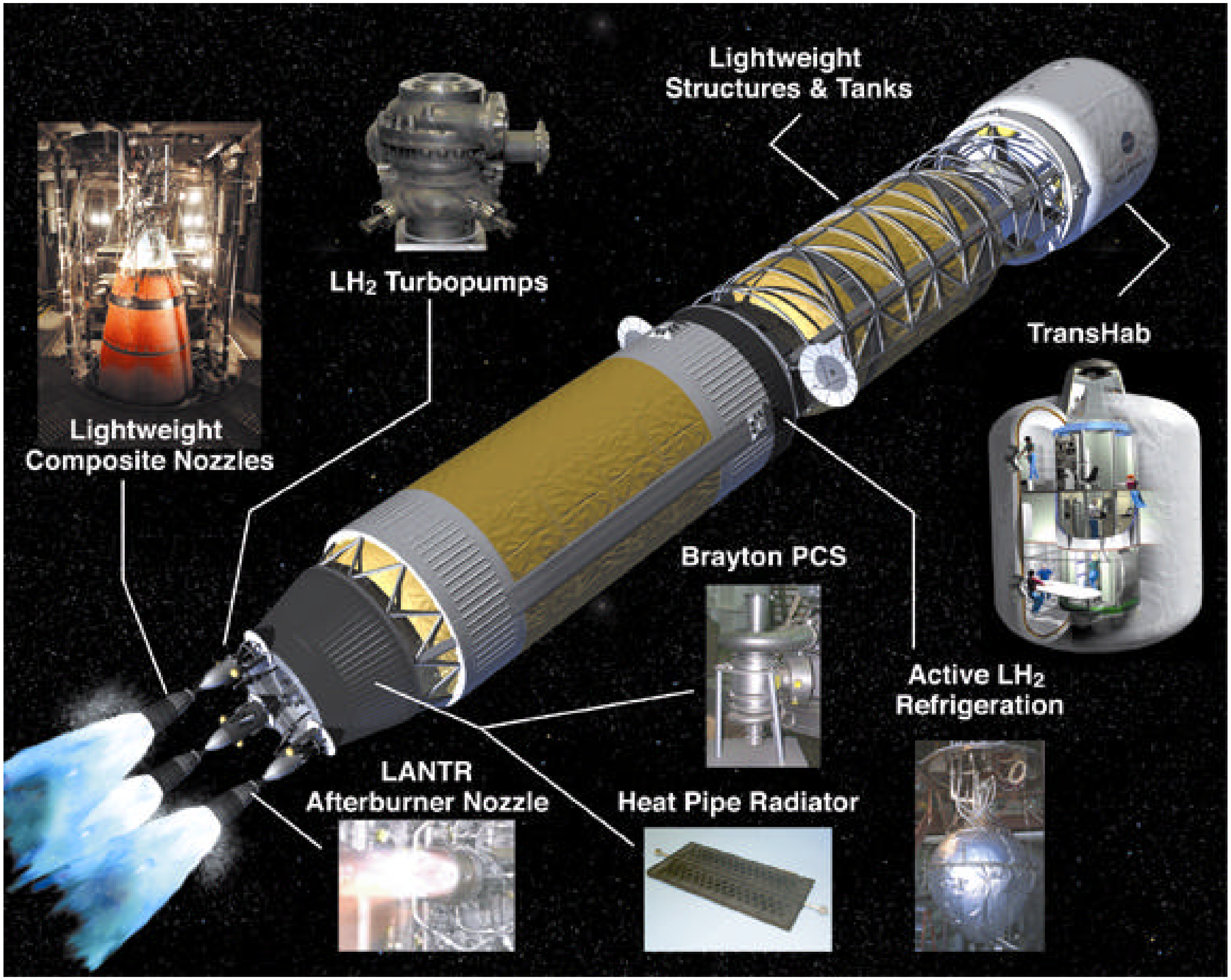
BNTR	BLANTR	NEP	NEP	NTR/EP
"SOA" Technology Brayton	**"SOA"** Technology Brayton	**"Mid-Term"** Technology Brayton	**"Far-Term"** Technology Brayton	**"Near-Term"** Technology BNEP-Brayton
Isp 955 sec	Smaller Vehicle	Specific Mass 5.6 kg/kWe	Specific Mass 3.9 kg/kWe	Specific Mass 13 kg/kWe
	Isp 955 sec	37 Mwe	11 Mwe	1 Mwe
	Isp 755 sec @MR=1	Isp 5200	Isp 4000	Isp 5000/4000
				NTR Isp 955

Space Transportation Project Office
Glenn Research Center

Fission Propulsion Technology Scaling for Science to Human Missions

Parameters	**Science Missions**		**Human Missions**		
	NEP	**BNTEP**	**BNTR**	**BNTEP**	**NEP**
Reactor Power	2.5		330/0.2		
Thermal (MWt)	.4 to .5	100/.4	330 to 550	330/2.5	44
Electric (kWe)	100-500	20-100	50	1000	11000
Engine Thrust			15	15	
Thermal Mode (klbf)		2 to 6	15 to 25	15000	
EP Mode (N)	2 to 5	1 to 3		30	300
EP Thrusters					
Power (kWe)	20 to 50	10 to 25		100 to 500	> 1000
Number	2 to 10	2 to 4		2 to 10	5 to 10
Brayton					
Power (kWe)	35 to 100	25	25	350	> 1000
Radiator Size (m2)	250	150	70	550	> 2500
Technology	SOA	SOA	Near	Mid	Far

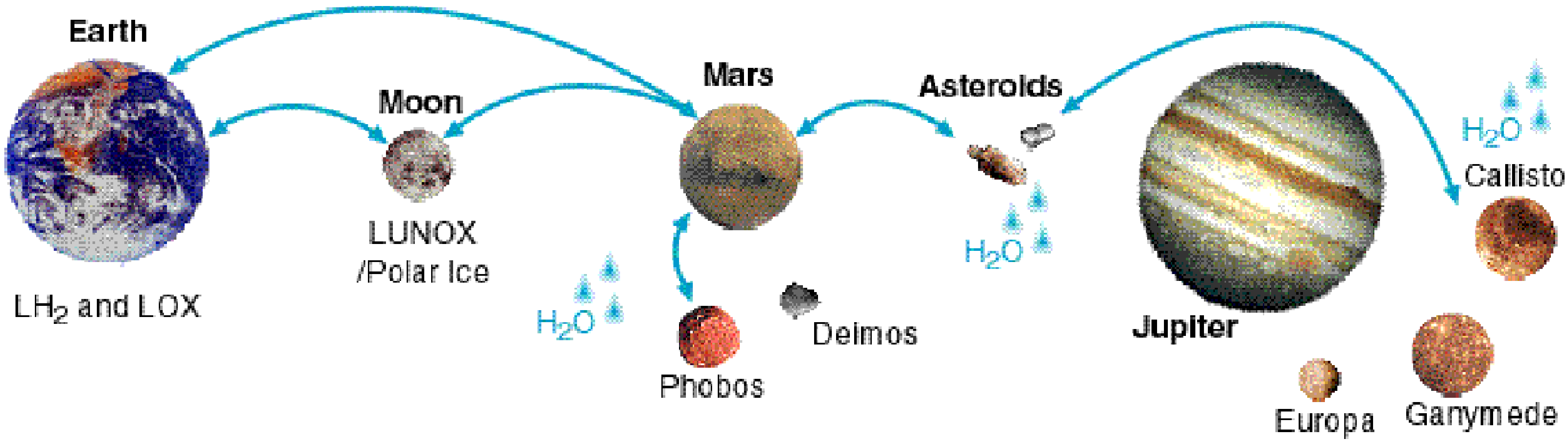
Technology Development is Underway to Support Design Definition for the BNTR Crew Transfer Vehicle



Potential Mission Applications

Human Exploration Possibilities Using NTR

High thrust and I_{sp}, power generation and ISRU allow significant downstream growth capability--"Revolution through Evolution"



- **Mission possibilities:**
  - Reusable Lunar and Mars Transfer Vehicles
  - "24 Hour" Commuter Flights to the Moon
  - Reusable Mars Ascent/Descent Vehicles

Viewgraph developed for Garry Lyles during ASTP formulation phase - 1996

Nuclear Propulsion Options for Moon / Mars Exploration

A variety of Moon / Mars mission architectural features (with initial focus on Mars) will be assessed

Mars Mission Architecture Features:

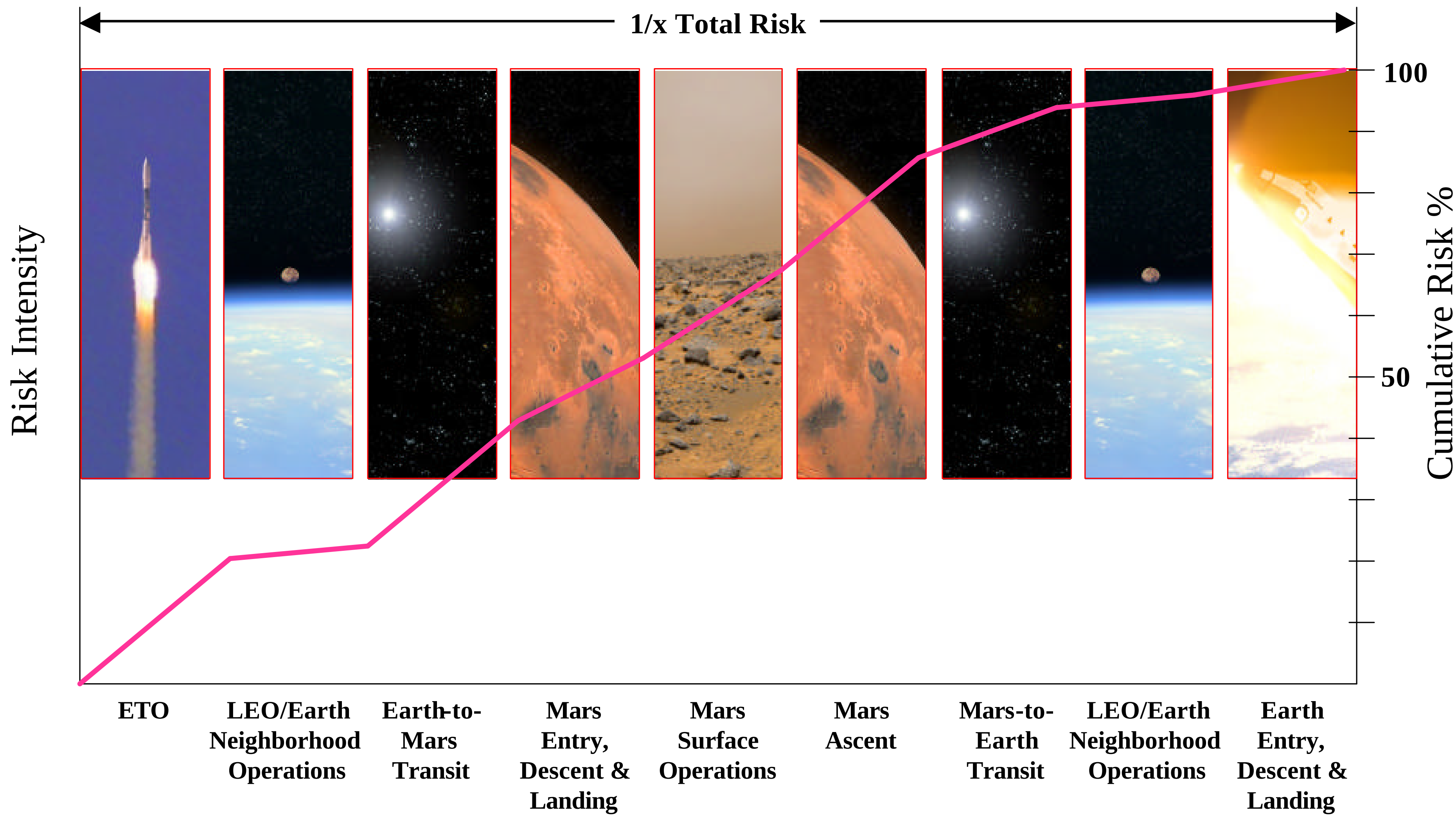
- Reusable transportation for both in-space and ascent/ descent
- LEO transportation node/depot and/or Earth-Moon L1 staging node
- BNTR, "LOX-Augmented" NTR (LANTR), "all" NEP and hybrid BNTEP options will be considered for piloted and cargo mission applications
- Will consider the use of reusable boost stages that provide Earth departure assist, then separate, retrofire and return
- Will take preliminary look at a mobile NEP tanker that can be positioned at either low Mars orbit or highly elliptical Mars orbits like those examined in NASA's DRMs
- Will consider the impact on vehicle design of a Phobos propellant depot. Previous GRC assessments showed that with resupply LOX and LH_2 from Phobos, an expendable bimodal LANTR MTV wouldbe capable of Earth return and reuse
- Other concepts / features as identified and that look promising

Nuclear Propulsion Option Conclusions

- **Development of a gas-cooled reactor fuel capable of bi-modal operation would leverage one fuels technology development to serve three propulsion technologies**
- **Hybridizing Bimodal NTP with EP can provide advanced technology performance for high energy missions with nearer term technologies**
- **Both NTP and NEP technologies are readily scalable**
  - **Small BNTR sufficient for scientific probe missions is within a factor of 2 of NTR technology required for Human Mars Missions**
    - 6000 lbf for Science vs 15000 lbf for Human Missions
  - **Brayton or Stirling power conversion for scientific probe missions is the same order of magnitude as that needed for Human Mars Missions**
    - 20-40 kWe for all NTR
    - 1000 kWe for BNTR/EP
    - 10000 kWe for all NEP
  - **Ion EP for sceintific probe missions is within a factor of 10 of technology required for Human Missions**
    - 10 kWe/Thruster vs 100 kWe/Thruster
    - 1000 kWe/Thruster required for all NEP

Cumulative Risk Intensity

Cumulative Crew Safety Risk Intensity Example



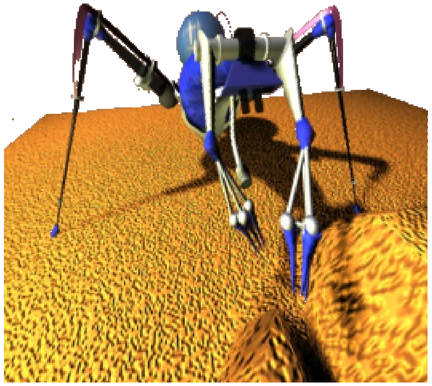
Risk Intensity Example

Mars-to-Earth Transit

- **Vehicle Systems**
- **Bioastronautics**
  - Environmental Health
  - Food & Nutrition
  - Bone Loss
  - Human Behavior & Performance
  - Radiation Effects
    - Carcinogenesis Caused by Radiation
    - Damage to Central Nervous System from Radiation Exposure
    - Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors
    - Early or Acute Effects from Radiation Exposure
    - Radiation Effects on Fertility, Sterility, and Heredity
  - Neurovestibular Alterations
  - Muscle Alterations & Atrophy
  - Cardiovascular Alterations
  - Immunology, Infection & Hematology
  - Space Medicine
  - Multi-system Alterations

NanoBioLogic Systems

- **Nanobiologics integrates nanotechnology, biotechnology, and information technology to achieve unprecedented capabilities in engineered systems**
- **CMU's Robotics Institute is assessing the utilization of NanoBioLogic systems to support both Human and Robotic missions**
- **Study will identify:**
  - Mission applications
  - Benefits
  - Concepts
  - System Technologies

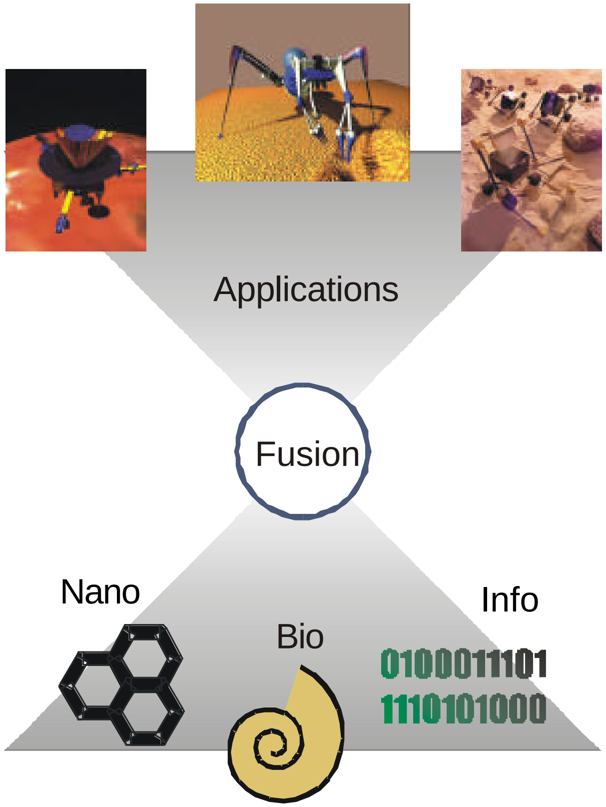


- **It is anticipated that NanoBioLogic systems will deliver unprecedented capabilities for the exploration of space, and for the study of the origin and role of life in the universe**
  - Small size, mass are unique payoffs for space
  - The reduced gravity of some space venues offers further space advantage
- **Nanobiologic technologies will also contribute immensely to macro-systems**

Nano/Bio/IT Fusion

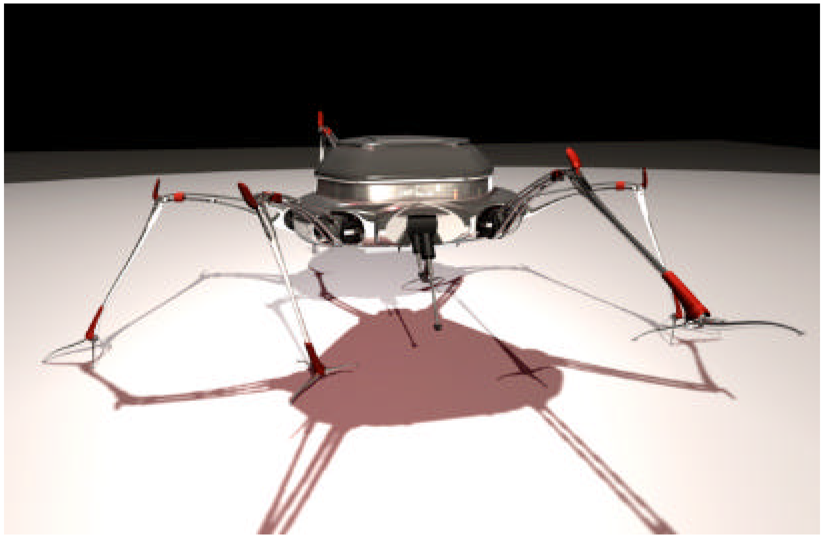
- **Fusion: integration of constituent materials and components**
  - **multiple scales (nano/micro/macro)**
  - **multiple domains (nano/bio/info)**
  - **chemical, bio, electrical, and mechanical, and data/info compatibility**
  - **tightly integrated biomimetic agents**

- **Objective: Manifest "nanobots" instantiation**
  - **miniature application-specific robots**
  - **micron sized components**
  - **nano/bio/infotechnology**



NanoBioLogic Fusion Objectives

- **Comprehensive integration of structure, sensing, power, actuation, communication, and processing**



- **Produce robots akin to small creatures with ability to**
  - **Acquire, process, and communicate information**
  - **Move and navigate and operate independently**
- **Designed and engineered for**
  - **Severe environments (e.g., vacuum, shock, radiation)**
  - **Manufacturability and repeatability**
  - **Mission-specific needs**

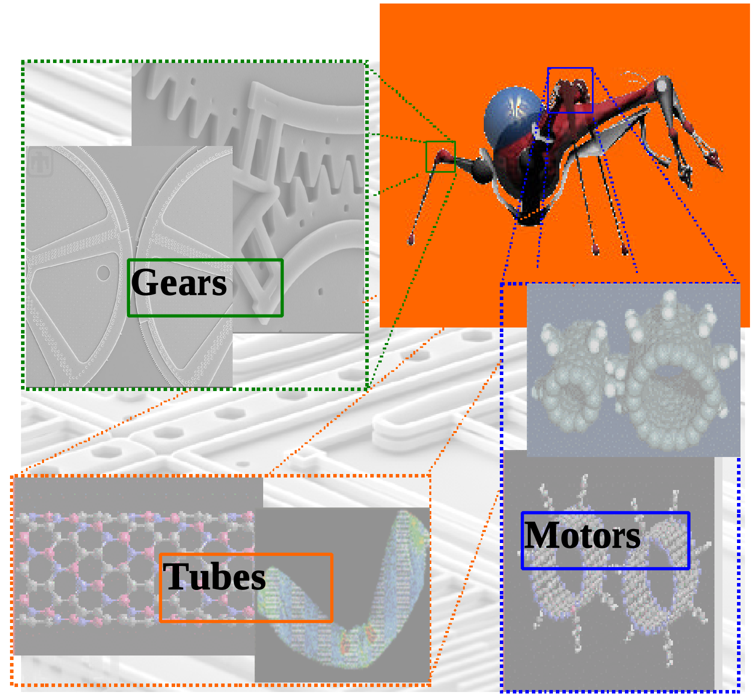
Fusion Challenges

- **No established design methodology**
- **Ad hoc, parochial technology development and one-of-a-kind components for integration**
- **Disparate prior nanorobotic designs**
- **Craftsman-like assembly**
- **Lack of focus on space applications for existing designs**

- **Missing or immature technology pieces**
  - Long-term lightweight power
  - Effective actuation for locomotion, sampling and manipulation
  - Self-healing information and communication subsystems
  - Biosensing modules that survive space environments

Fusion Approaches

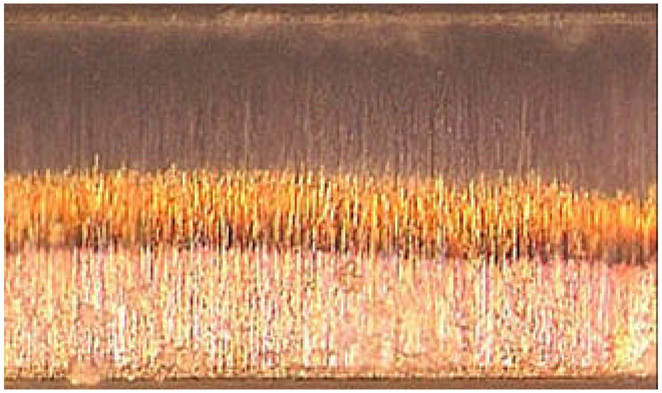
- **Develop nanobiologic design methodology**
- **Leverage expertise in robotic system design, development and deployment**
- **Evolve software incubator for system-level discovery and evaluation maturing to physical implementation**
- **Develop micro/nano assembly and self-assembly**



- **Identify, acquire, and merge "best-of-breed" technology**
  - **COTS, academic, industry, government labs**
  - **Continuous evaluation of advances**
  - **Guide Institute research to fill in technological gaps**

Power: System Technology Options

Power System - Technology	NASA TRL	Mission Payoff
Thin Film Batteries	3	6
Supercapacitors	2	7
Micro-Fuel Cells -Solid Oxide Fuel Cell (SOFC) -Direct Methanol Fuel Cell (DMFC)	 2 2	 9 9
Photovoltaic Cells -Si -Nanocrystalline rods -Tri-Block Co-Polymers	 3 2 1	 3 6 6
Thermoelectric Generators	2	6
Kinetic Generators	1	4
Microturbine Engines	1	7

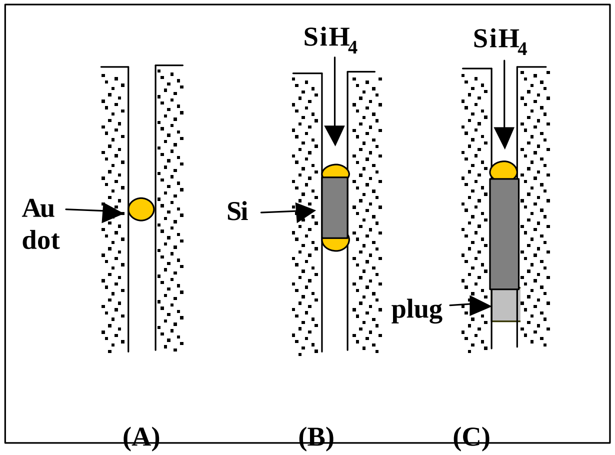


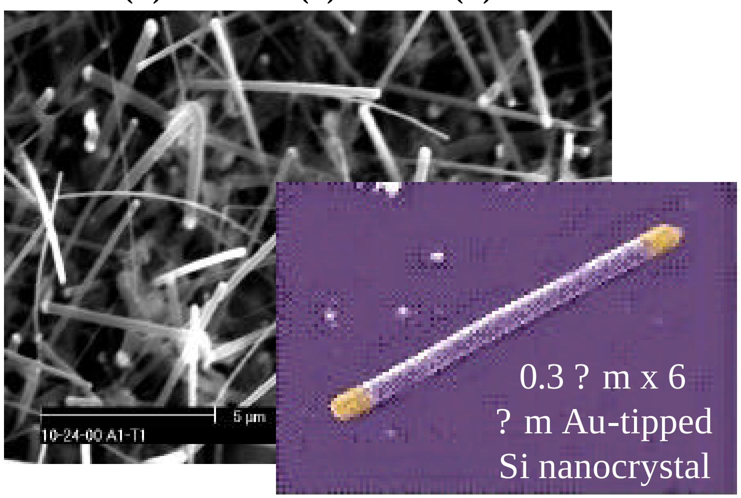
Striped nanorods bimetallic replaceable power source placed on board units
20-400 nm diameter,
10’s mm long

Striped Nanorods

Power: Devices

Single crystal photovoltaics

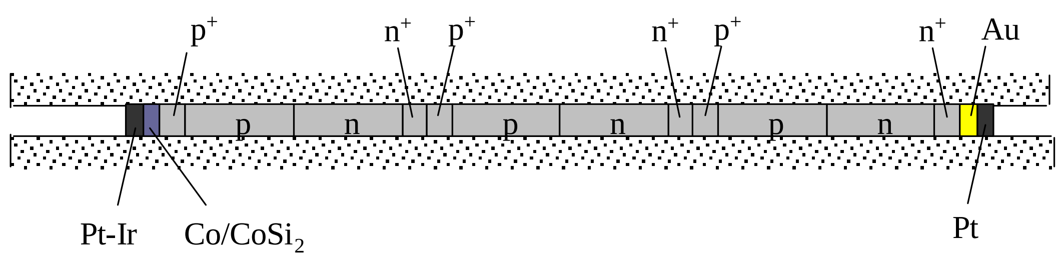




CVD Growth of Si Nanocrystals in Porous Alumina Membranes

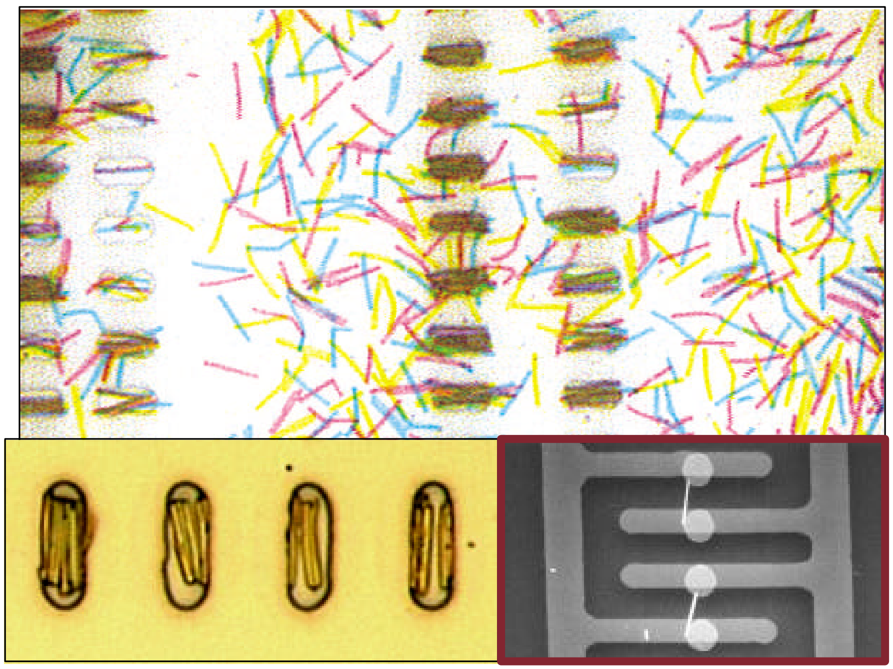
- Efficient solar conversion
- Radioisotope-phosphor systems for dark power generation

- Single crystal synthesis is straightforward at the micron scale
- Single crystal efficiencies (ca. 15%) should be achievable in multi- p-n junction devices



Power: Assembly and Scaling

Assembly: Electrofluidic and microfluidic techniques have been developed for nanowire device integration



Scaling: Minimum scale will be determined by absorption lengths:

- 5 - 20 mm for indirect gap (Si, Ge) semiconductors
- 0.2 - 1 mm for direct gap (CdTe, $CuInSe_2$) materials
- 1 - 10 mm for radiophosphors

Developing and Integrating Sensors

- Themes:
  - *Detect rare targets in difficult environments*
  - *Use biomimetics to develop extraordinarily sensitive, cheap and robust sensors*

- **Geological components on planets**
- **Life-related molecules**
  - **Planets**
  - **Space traveler health**
  - **Harsh environments on earth**
- **Leakage on spaceship**
  - **Vacuum, fuel, oil leaks on spacecraft**

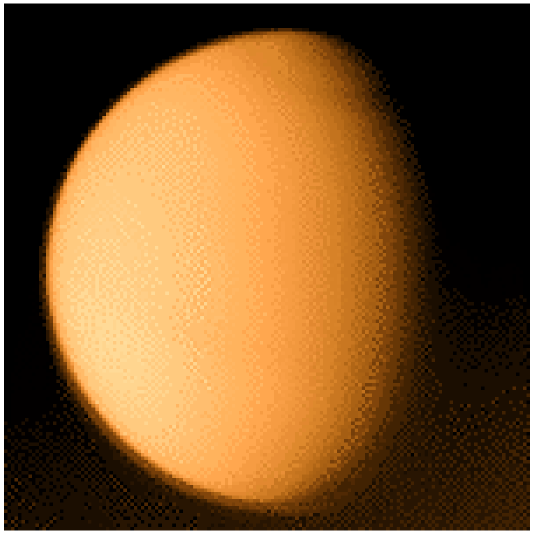
Step 1: Sampling in a Difficult Environment

- **Sampling Challenges**
  - **High and low temperatures**
  - **Vacuum**
  - **Below surface**
  - **UV exposure**

- **Sampling Approaches**
  - **Drill or crush materials for sample**
  - **Sticky "tongues" for sampling**
  - **Non-evaporating molecular trap: "saliva"**
  - **Fluid polymers**
  - **Low-vapor-pressure liquids—glycols, alcohols, ionic liquids, eutectics?**

Movement Options

- **Walking**
  - Insect mode - six legs with triangular gait is most useful
- **Crawling**
  - Many small MEMS feet (starfish, snail)
- **Hopping**
  - Especially good for low-gravity bodies (grasshopper)
- **Flying**
  - On Mars; on Titan? On gas giants
  - May be very useful inside space vehicles, space station
- **Reaction motors**
  - Small jets (from internal stores—heat for propulsion
  - Ion thrusters
  - Photon thrusters for very low-G environments
- **Solar sails**
  - Sails powered from motherbot



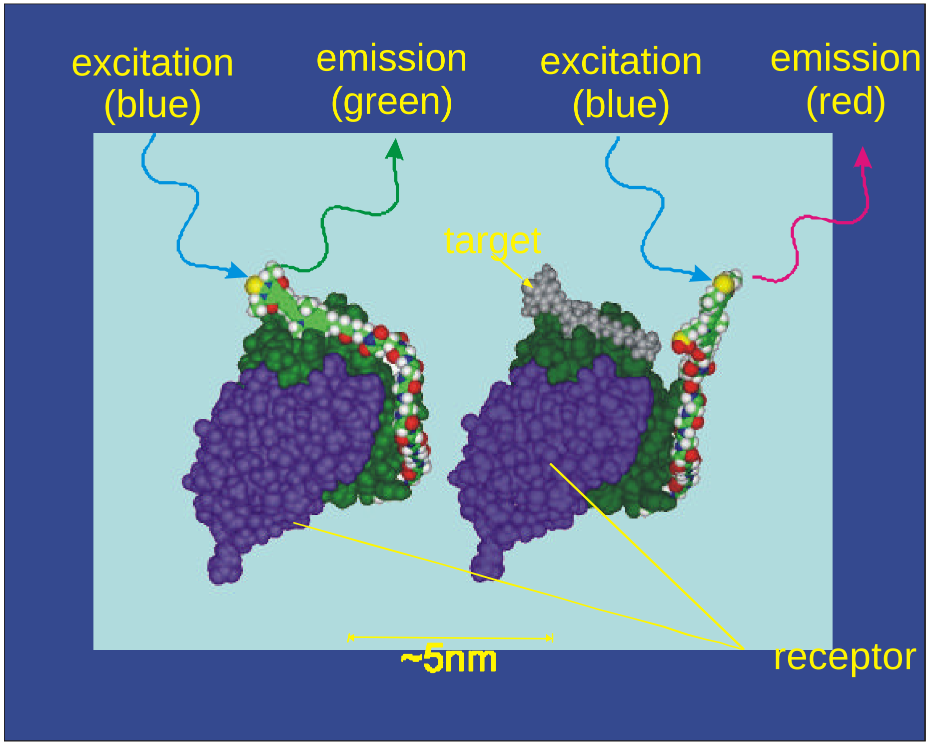
Step 2: Sensing and Analysis

- **Targets – Analytical methods**
  - **Biological polymers – Biosensors, mass spec, SERS, chirality sensors, etc**
  - **Morphology of life "forms" in ice/rock – Imaging**
  - **Cytokines in astronauts – Biosensing array chips**
  - **Bone loss in astronauts – Stress response sensors, imaging**
  - **Radiation damage to cells and tissues – Biosense response signals, apoptosis, cell division aberrations, chromosome abnormalities**

Examples of Binding-Type Sensors

Target recognition and signal transduction

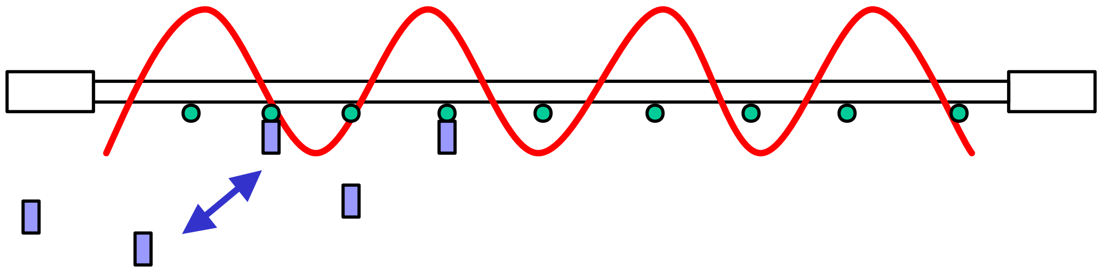
- **Target Recognition**
  - Peptides: antibody-related
  - Nucleic acids: aptamer related
  - Inorganic-organic receptors

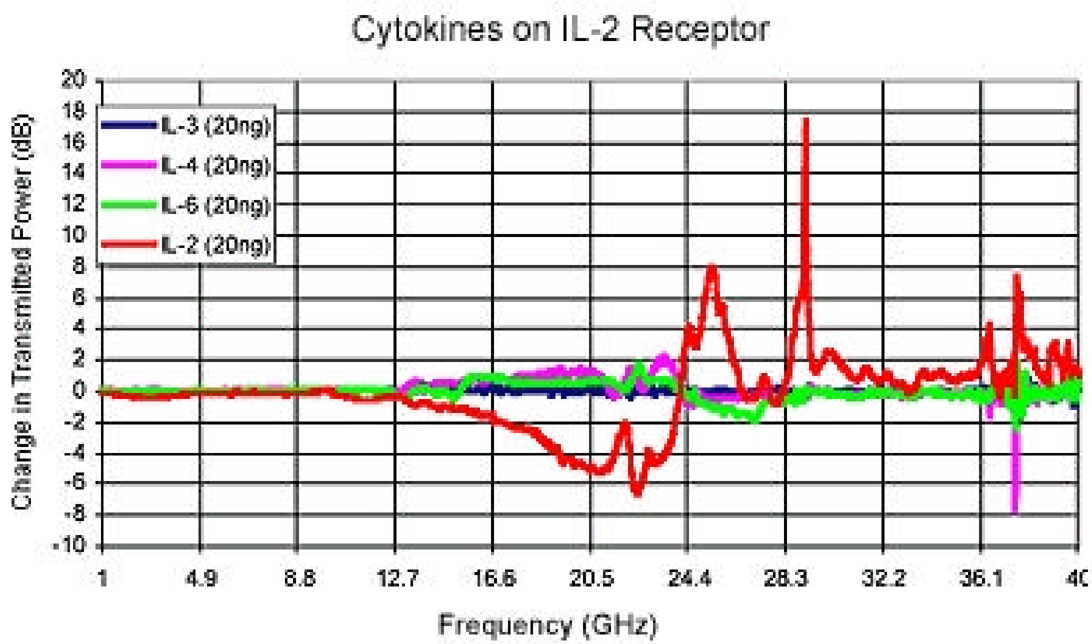


- **Signal Generation**
  - Fluorescence
  - RF detection
  - Mass change
  - Refractive index
  - Calorimetry

Strip Line Sensor Technology for Binding-Type Sensors

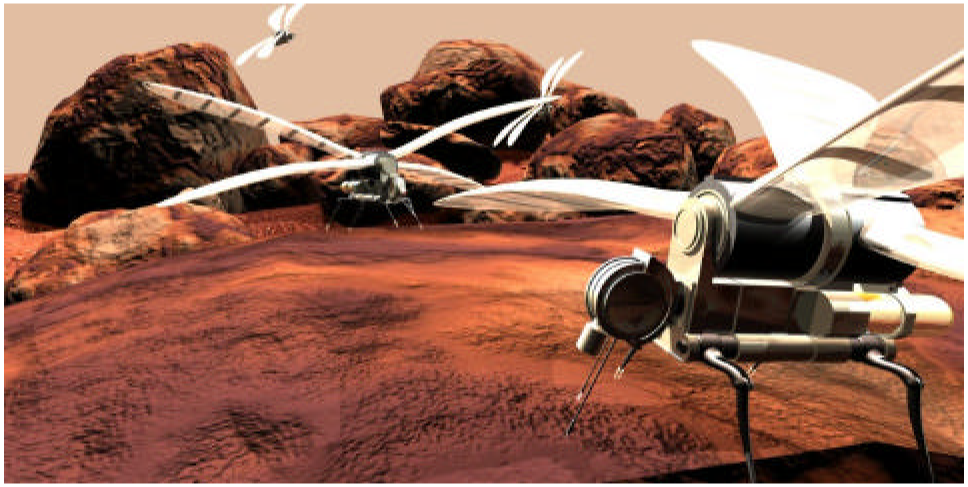
Label-less methodology for sensing biological and non-biological molecules in 100-100,000 Dalton molecular weight range





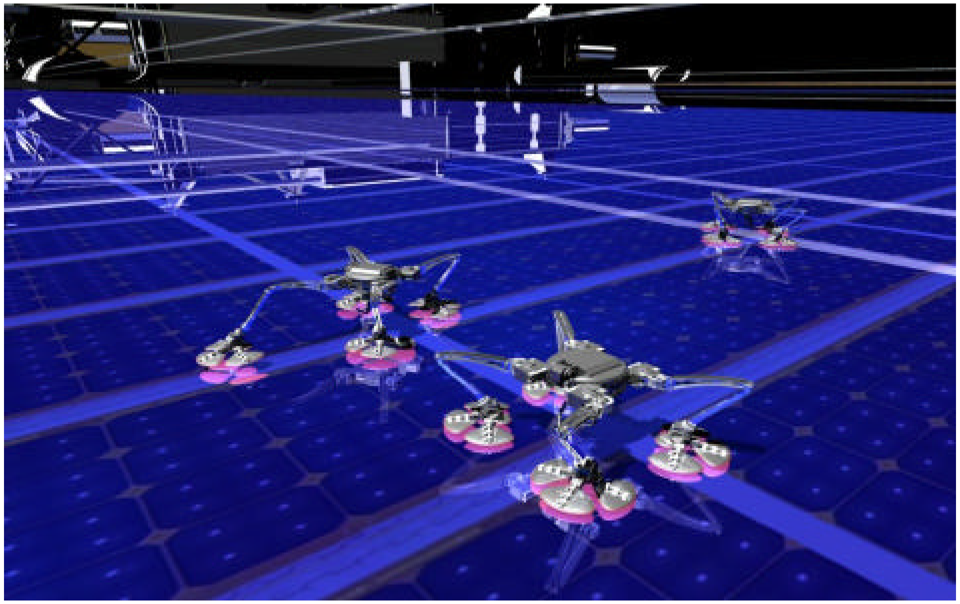
Search for Life on Mars

- **Nanobot with following sensor systems:**
  - **Extraction and sensing of biopolymers**
    - Repeating element sensor
    - Micro-mass spec
    - Micro-Raman
  - **Molecular chirality sensor**
    - Binding recognition
    - Optical rotation of concentrated extracts
  - **Remnants of life forms**
    - Rock cleavage device with
    - Image scanner/pattern recognition
    - Raman analysis of identified structures



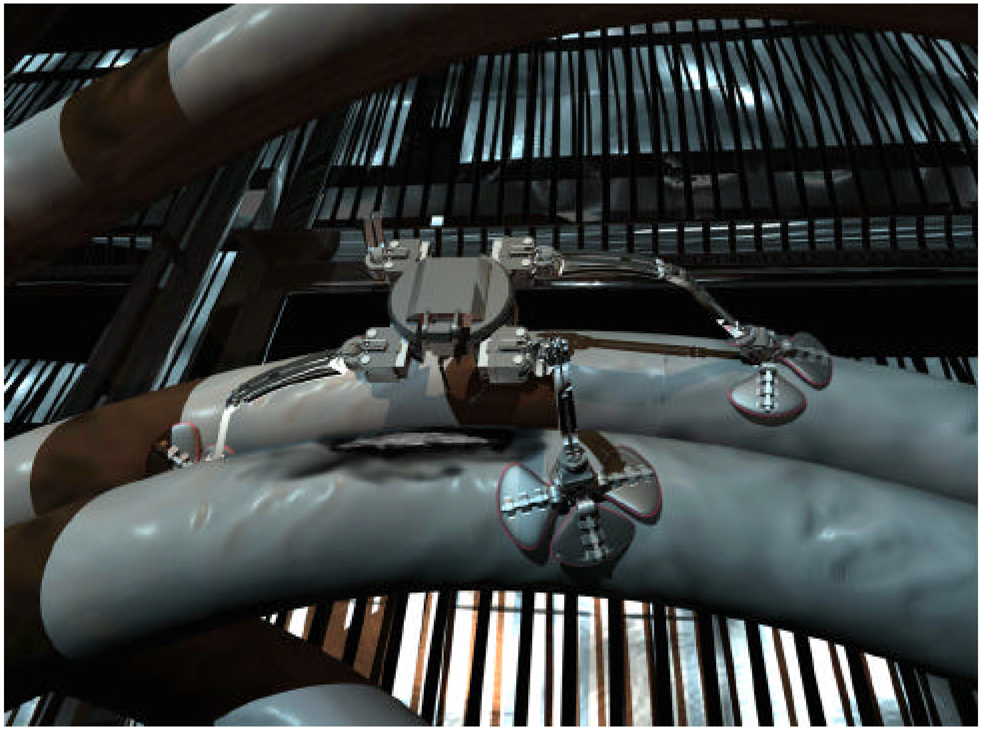
Mechanical-Electrical Diagnostics on Spacecraft

- **Nanobot with following sensor systems:**
  - Vibration sensing
  - Position sensing
  - Electrical hot spot detection
  - Resistance, impedance,
  - voltage measurements
  - Gas-vapor release sites
  - Radiation hot spots



Mechanical-Electrical Repairs on Spacecraft

- **Nanobot with following sensor systems:**
  - Position sensing
  - 3-D mapping and adaptive positioning
  - Proprioception
  - Force, temperature, pressure sensors on manipulators
  - Power for manipulators
  - Vibration sensing
  - Gas-vapor release sensing
  - Radioactivity sensing



Human & Robot Cooperative Teams

J. H. Smith
G. Rodriguez
J. Geffre
R. Ambrose
C. Weisbin

May 3, 2002

Objectives

- **Develop new system architecture concepts of cooperative teams of humans and robots operating beyond low-Earth orbit**

- **Quantify the impact and benefits enabled by new human-robot system architectural concepts in performing a range of futuristic space operations (in-space telescope assembly)**

- **Conduct case study to illustrate how the new human-robot system architectures provide benefit to in-space structural platform assembly scenarios.**

Revolutionary Architectures Enabled by EVA/Robot Technologies

- JPL GOAL IS TO ILLUSTRATE THE PREMISE THAT THE WHOLE IS GREATER THAN THE SUM OF THE PARTS

  - REVOLUTIONARY advances in both EVA & ROBOT technology lead to Human-Robot Cooperative SYSTEM ARCHITECTURE GAINS greater than those of the individual technologies

SUPER-ROBOT
- Nano-Tech Self-Repair
- Self-Healing
- Skin Sensitive
- Etc.

+

SUPER-HUMAN
- Suit-Augmented
- Force Multiplied
- Zoom In/Out See
- Etc.

SUPER-HUMAN-ROBOT ARCHTECTURES
- 1 Controller Commands Work Crews
- Nano-to-Macro Scale Operations
- Minimalist Resources
- Heavy-Duty Large Force Tasks
- Etc.

Revolutionary SUPER-HUMAN Skills

Functions	In-Space SOA Performance	Revolutionary Performance
BREATHE	Heavy Back-Pack	Miniaturized ISRU Unit
WALK	Suit-Impaired	Suit-Augmented
TALK	Discrete/Selected Sites	Distributed/Selectable; wide-bandwidth
GRASP	Glove Impaired	Glove Augmented
HOP	Short range; unsafe	Long range; safe
TOUCH	Glove Impaired	Glove Augmented
SEE	Daylight; headgear impaired	Day/Night; Multi-Spectral; Zoom In/Out
THINK	Supreme	Supreme-Plus-Plus
THROW	Suit Impaired	Suit Augmented
OTHER	Limited by Human Physiology & Suit	Expands Range of Natural Human Skills

Revolutionary SUPER-ROBOT Skills

Functions	In-Space SOA Performance	Revolutionary Performance
SURVIVE	Solar Power	Withstand Extreme Environment
MOVE	Benign Environment	High-Risk Environment
COMMUNICATE	Discrete/Selected Sites	Distributed/Selectable; wide-bandwidth
GRASP	Few DOF; small force	Many DOF; large force
HOP	Limited Range; unsafe	Unlimited Range; Safe
TOUCH	Point Sensors	Distributed Skins
SEE	Daylight; headgear impaired	Day/Night; Multi-Spectral; Zoom In/Out
THINK	Moderate	Supreme
LIFT	Low-g Heavy	High-g Heavy
WORK	Focused on Human-Scale Robot; some R & D on miniaturization	Expands Range in size, perception, cognitive and motor skills

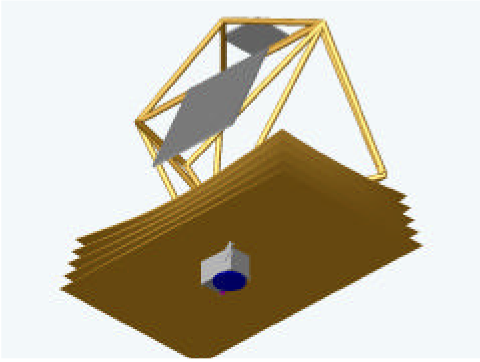
SUPER HUMAN+ROBOT ARCHITECTURES

(One Plus One = 999 Billion)

Functions	In-Space SOA Performance	Revolutionary Performance
ASSEMBLE	Remote Robot Controlled from Earth or LEO	1 Controller Commands Many Robot-Human Teams at Once
MANIPULATE	SRMS & ISS RMS	1 Controller Commands Human-Robot Work Crew
ACCESS	10s of Meters	Multi-Scale; from Nano-to-Macro Scales
WORK	Servicing & Assembly in LEO	Heavy-Duty Assembly of Telescopes & Other Ultra-Precise Structures
INTERACT (Human & Robot)	Limited-Autonomy; teleoperation	Minimalist; highest-level commands
COOPERATE	Robot Manipulator Assists Astronauts	Cooperative Human-Robot Teams (beyond LEO)

Illustrative Case Study: Gossamer-Type Telescope Assembly

- Establish baseline performance with State-of-the-Art EVA & Robot Technology
- Identify set of REVOLUTIONARY technologies to be evaluated
    - Self-Repairing Autonomous Robots
    - Self-Healing Nano-Tech Based Materials
    - Etc.
- Quantify performance benefits of a few selected REVOLUTIONARY TECHNOLOGIES within a system context



Dual Animorphic Reflective Telescope (DART) Concept

•Major Structural Parts
•Primary Structure
•Secondary Structure + Instrument Platform
•Inflatable Reflector Structure
•Telescope/Bus Interface Structure
•Isolation System
•Solar Array Structure
•Solar Array Actuators
•Solar Array Latch/Release
•Antenna Articulation Mechanism
•Integration Hardware
•Balance Mass
•Interface Adapter to Secondary Spacecraft
•Adapter, Launch Vehicle Side

•How to Get Whole from its Parts?

Task Steps & Status

1. ✓Done — **Baseline FAIR Assembly Sequence**
2. ✓Done — **Identify Task Primitives**
3. ✓Done — **Identify Performance Parameters**
4. Current — **Define Work System Technology Candidates**
5. Current — **Sort Parameters:**
   - •Performance
   - •Technology
6. Current — **Model Performance of Task Primitive = f(Parameters)**
7. Current — **Build Spreadsheet Models for Task Primitives**
8. Current — **Est. Parameters for current and advanced Technologies**
9. **Define resources, dependencies for task primitives**
10. **Integrate task primitive models with resource models**
11. **Compare technology impacts**
12. **Draw Observations:**
    - •Technologies
    - •Tasks
    - •Primitives
    - •resources

EVA

PROJECT

OFFICE

FY02 RASC Status
Advanced EVA Capabilities Study

Richard Fullerton

NASA JSC/HQ

Joe Kosmo

NASA JSC

May 3, 2002

RASC EVA Study Purpose

The basic scope of this effort is to produce a comprehensive report that identifies various design concepts for human related advanced EVA systems necessary to achieve the goals of supporting future space exploration and development customers in free space and on planetary surfaces. The design concepts to be studied and evaluated will not be limited to only anthropomorphic space suits, but will be broad enough to include a wide range of human-enhancing EVA capability technologies as well as consideration of optimized coordination with advanced robotics.

The study effort will establish a baseline technology "road map" that will attempt to layout an investment and technical development strategy including recommendations that would lead to enhanced synergistic human/robot EVA operations for future space missions by the 2020+ timeframe. The overall objective of this study effort will be to focus evolving performance capabilities of the various EVA system elements towards the goal of providing high performance human operational capabilities for a multitude of applications and destinations.

RASC EVA Study Forward Work

- **SAIC**
  - Develop annotated outline of proposed report (due August 15, 2002)
  - Identify EVA topic areas and proposed graphics (supported by JF&A)
  - Gather EVA/robotic related text and graphics from existing sources
  - Compile/develop and edit text sufficient to provide appropriate narrative information for completion of the annotated outline.
  - Compile final report including electronic file and reproducible paper copy (due December 15, 2002).

- **JF&A**
  - Prepare updates and changes to the existing JF&A Exploration EVA database
  - Prepare new computer graphics of advanced human/robot EVA systems
  - Prepare updates to current human/robot EVA system animations
  - Develop new "beyond the next generation" EVA human/robot system topics
  - Prepare high resolution still photo illustrations for print/reproduction

- Report media to include summary presentation. Both CD and hardcopy will contain report details. Web edition to be posted at http://jsc.nasa.gov/xa/advanced.html

Astronaut-aided Construction of a Large Lunar Telescope

Michael B. Duke
Center for Commercial Applications of Combustion in Space
Colorado School of Mines

May 3, 2002

Participants

- **Michael B. Duke, CSM, Principal Investigator**
- **Robert King, CSM Engineering Division, Co-I**
- **Paul van Susante, CSM, Graduate Research Asst.**
- **Yuki Takashi, CSM, Summer Visiting Student**
- **Jeffrey van Cleve, Ball Aerospace Corp., Astronomy Advisor**

Objectives

- **Define rationale for building very large (post NGST) telescopes on the Moon**
- **Address environmental constraints of lunar surface construction**
- **Adopt a baseline design for a very large telescope**
- **Develop concepts for manufacturing, emplacement, and operation of the telescope**
- **Assess the roles of humans and machines in telescope construction, operation and maintenance**
- **Characterize factors that dominate cost of constructing and operating a very large lunar telescope**

Approach

- **Definition of lunar telescope based on studies in literature and discussions with van Cleve; environmental characteristic literature review.**
- **Lunar telescope emplacement process builds on lunar polar IR telescope designed by P. v. Susante as MS thesis at U. Delft.**
- **Construction tasks will be identified and characterized with respect to complexity, repeatability, etc.; mix of humans/robots to complete tasks will be allocated, based on current and predicted states of art.**
- **Analysis of potential costs will include DDT&E, transportation, maintenance, repair and upgrading**

Project Status

- Work will begin on project on May 6 (start of summer session at CSM) (if contract is in place)
- Telescope definition discussions with J. Van Cleeve – May 3 (Van Cleve's time is being contributed by Ball Aerospace)
- P. v. Susante will coordinate Lunar Telescope Design Project at ESA Lunar Base Design Workshop, June 10-21, at Noordwijk

Life Detection Requirements Definition and Revolutionary Instrument Concept Development

David McKay
NASA JSC

May 3, 2002

Search for Life on Mars

- **Objective**
  - **Define concepts for exploring for life on Mars**
    - Initial robotic exploration
    - Precursor to Human missions
    - Human missions
  - **Define science requirements to a level sufficient to support a wide range of initial concept development**

- **Vision**
  - **Find present or past life on Mars**
  - **Use this discovery to catalyze major human exploration program**
  - **Establish permanent science base on Mars**
  - **Evolve toward colonization**

Search for Life on Mars

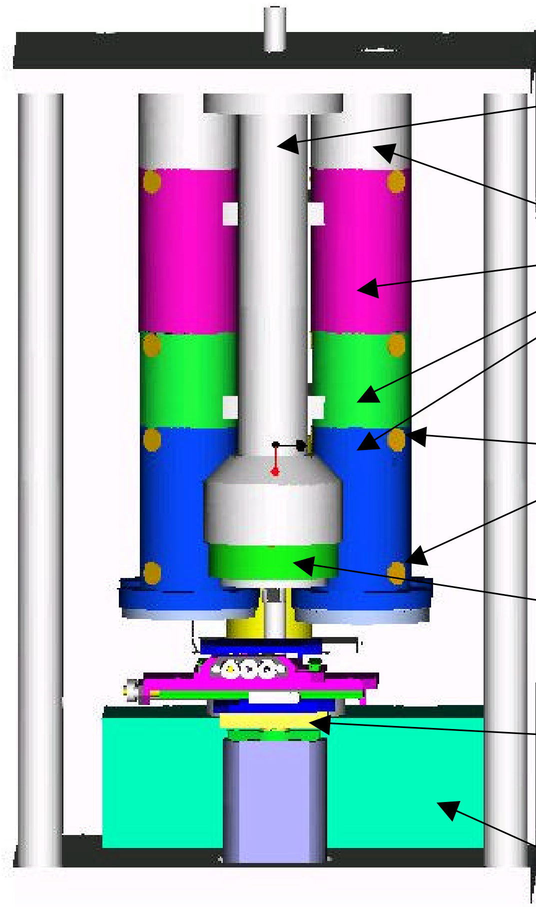
- **Approach**
  - **Define science requirements for searching for life**
    - Start with MEPAG
      - **Take MEPAG requirements to next level down**
      - **Emphasis on environments for existing life-first priority**
      - **Emphasis on environments for past life-next priority**

- **Instrument and Mission Approach**
  - **Start with current concepts for microarray system for detecting organic compounds (see next chart)**
  - **Determine potential discovery data related to life on Mars**
  - **Generate requirements for “golf ball” size instrument**
  - **Generate mission design for deploying this technology**

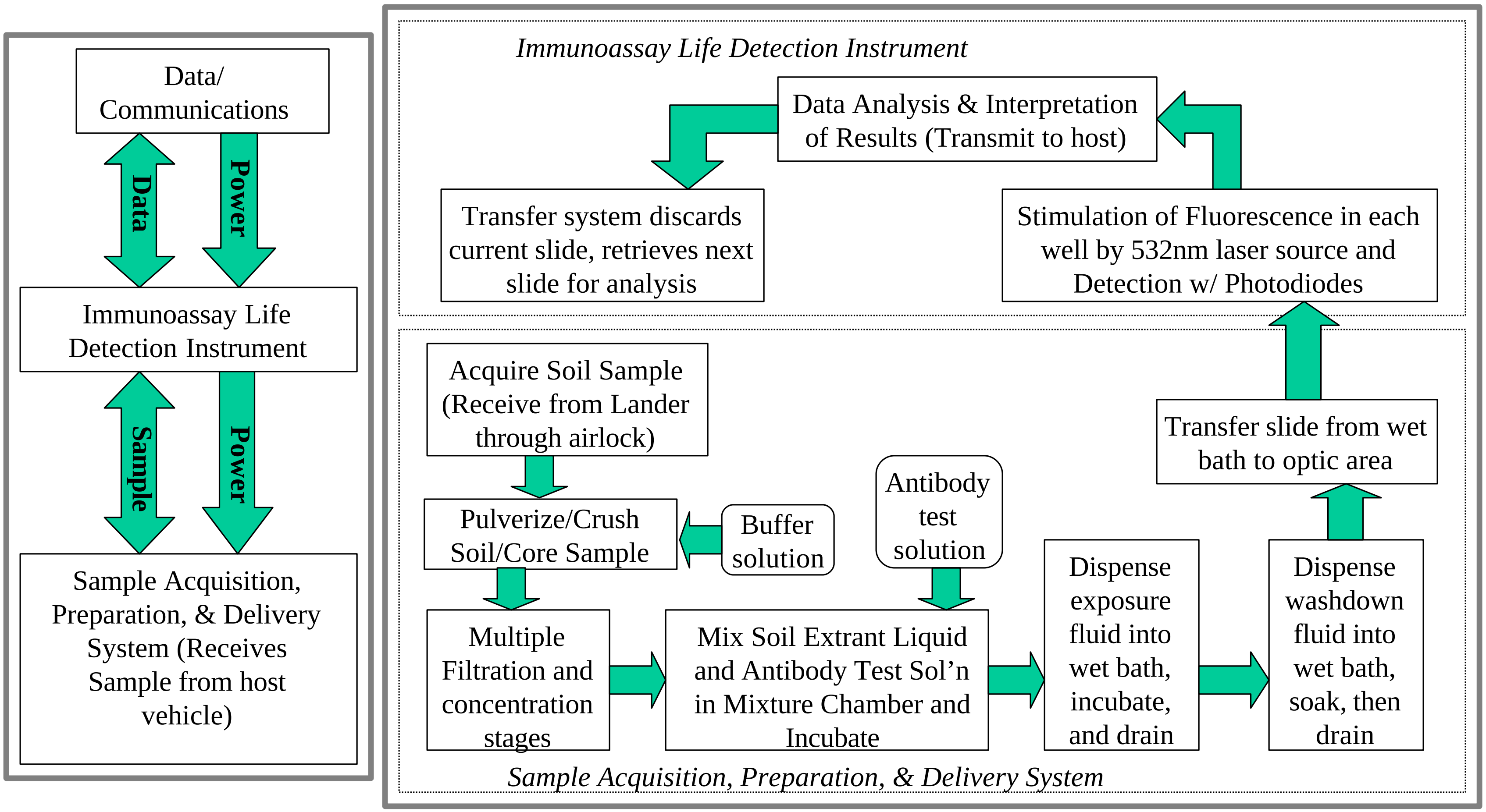
Instrument Overview

- **Detects biomarkers in soil samples**
- **Volume: 10"tall x 6"wide x 8"deep**
- **Approx. Mass: 30 lbs., assuming all components made of solid 316 stainless steel (titanium would be much lighter)**
- **Power: Estimated 15-20 Watts maximum at any given time**

MICROARRAY ASSAY FOR SOLAR SYSTEM EXPLORATION (MASSE) Current design concept



MASSE Functional Task Diagram



Study Approach

- **Assign technical lead with appropriate skills to develop golf ball instrument concept**
- **Evaluate latest technology in microfluidics**
- **Continue acquisition and testing of antibodies**
- **Gather and define mission concepts and requirements to deliver and use golf ball instruments**

Study Approach – Near term

- **Near term**
  - Have identified Lockheed person with space hardware experience and biology background and have ‘borrowed’ her for the next 4 months
  - Have identified several companies specializing in microarrays, microfluidics, and hardware development
  - Have located a technical conference on microfluidics in July and have assigned three people to attend, learn, make contacts, and report
  - Will work with current MASSE design to miniaturize from current desk-PC size to golf ball size
  - Biggest breakthrough will be application of microfluidics to replace existing component (tanks, tubing, mechanical pumps, valves, etc.) design
  - Will work with appropriate vendor on new design
  - Will provide concept design for mission integration

Study Approach – Mid term

- **Mid term**
  - Will continue to define science requirements
  - Will start choosing candidate sites by consultation with Mars science community
  - Will evaluate probabilities for detecting life
    - White paper and publishable manuscript
    - Charts
  - Will bring in rest of MASSE team for brainstorming, instrument design, target compound choices, extraction techniques

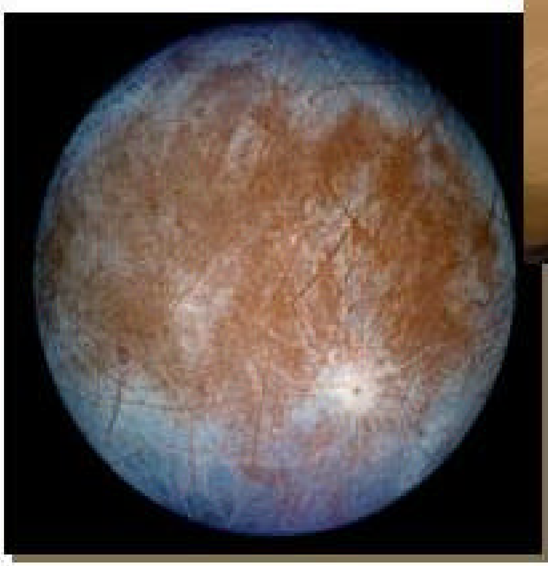
Products

- Written reports or charts
- Presentations
- Mockup of instrument
- Help with proposal for mission
- Help with presentation of science objectives
- Help with astrobiology community communication
- Communication and discussions

Back Up Information

To Explore the Universe and Search for Life

- Exploring the Universe and the life within it… enabled by technology, first with robotic trailblazers, and eventually humans… as driven by these compelling scientific questions:
  - How did we get here?
  - Where are we going?
  - Are we alone?



Science-Driven Process

To Explore the Universe and Search for Life

- Decisions are Science-Driven, not Destination-Driven
- Human presence beyond LEO will be enabled as a means to scientific exploration, not an end in itself

Enterprise Strategic Plans

- Office of Space Science (OSS) Themes & Missions
    - **Origins (Space- & Ground-based Observatories)**
    - **Structure & Evolution of the Universe (explores time, gravity, matter and energy)**
    - **Solar System Exploration**
        - **Astrobiology**
        - **Mars Exploration Program**
    - **Sun-Earth Connection (Sun's effects on solar system, life, and society)**

- Office of Space Flight (OSF) Themes & Missions
    - **Human Exploration & Development of Space**
    - **International Space Station**

Enterprise Strategic Plans: OSS Themes & Missions
Solar System Exploration

- Quests "Framework"
  - Explore formation & evolution of our solar system and the earth within it
  - Seek the origin of life and its existence beyond earth
  - Chart our destiny in the solar system
- Missions
  - Outer Planets Program: Studies organic-rich environments, prebiotic chemistry, & possible habitats in outer solar system (e.g., Cassini/Huygens, Europa Orbiter, Galileo-Europa, Europa Lander…)
  - Mars Exploration Program
    - **Scientific Goals:**
      - Search for evidence of past or present life
      - Characterize climate & geology
      - Prepare for human exploration
    - **Includes global surveys, in situ science, sample return, subsurface explorers, robotic outposts…**
    - **Technology Program (e.g., sample handling, propulsion, autonomous control…)**
  - Discovery Program: Community-define, competitively-selected, innovative, high priority, rapid definition missions (e.g., Mars Pathfinder, NEAR…)

Enterprise Strategic Plans: OSS Themes & Missions
Astrobiology

- **Key major unifying scientific goal across Science Themes**
- **Addresses 3 Fundamental Questions:**
  - How did life begin and evolve?
  - Is there life elsewhere in the universe?
  - What is the future of life on Earth and beyond?
- **Astrobiology Roadmap: Provides Science goals & objectives**
- **Astrobiology Program**
  - **Research & Analysis**
    - **Exobiology, Evolutionary Biology, & NASA Specialized Centers of Research & Training**
  - **NASA Astrobiology Institute (at ARC)**
  - **Technology & Development**
    - **Astrobiology Science & Technology Instrument Development (ASTID)**
    - **Astrobiology Science & Technology for Exploring Planets (ASTEP)**

Enterprise Strategic Plans: OSS Themes & Missions

- Origins
  - Defining Science Questions:
    - **(1) Where do we come from? (2) Are we alone?**
  - Goals:
    - **To understand how galaxies formed in the early universe**
    - **To understand how stars & planetary systems form & evolve**
    - **To determine whether habitable or life-bearing planets exist around other stars**
    - **To understand how life forms and evolves**
  - Missions:
    - **Space-Based Observatories: HST, FUSE, SOFIA, SIRTF, ST3, SIM, NGST, TPF, LF, PI**
    - **Ground-Based Observatories: Keck, Keck Interferometer, Palomar Testbed Interferometer**

Enterprise Strategic Plans: OSS Themes & Missions
Astrobiology

- **Astrobiology Science Program: Office of Space Science, Hqtrs**
- **Dr. Michael Meyer, Astrobiology Discipline Scientist**
- NASA Astrobiology Institute (NAI) at ARC
- NAI Focus Groups
  - Astromaterials
  - Europa
  - Evolutionary Genomics
  - Mars
  - Mission to Early Earth
  - Mixed Microbial EcoGenomics
- **International Affiliates**
  - UK Astrobiology Forum
  - Australian Cntr for Astrobiology

NAI Lead Research Teams
  - ARC
  - Arizona State University
  - Carnegie Institution of Washington
  - Harvard University
  - Jet Propulsion Laboratory (1)
  - Johnson Space Center
  - Marine Biological Laboratory
  - Pennsylvania State University
  - Scripps Research Institute
  - University of California, Los Angeles
  - University of Colorado, Boulder
- **New NAI Research Teams**
  - Jet Propulsion Laboratory (2)
  - Michigan State University
  - University of Rhode Island
  - University of Washington

Astrobiology Roadmap

The Astrobiology Roadmap provides guidance for R & T development across several NASA Enterprises:

- Space Science
- Earth Science
- Human Exploration & Development of Space

Three basic questions

- How does life begin and evolve?
- Does life exist elsewhere in the Universe?
- What is life's future on Earth and beyond?

- **Formulated into 17 specific science objectives, which have been translated into NASA programs and integrated with NASA strategic planning.**

How does life begin and evolve?

1. **Sources of organics on Earth. Determine whether the atmosphere of the early Earth, hydrothermal systems or exogenous matter were significant sources of organic matter.**

2. **Origin of life's cellular components. Develop and test plausible pathways by which ancient counterparts of membrane systems, proteins and nucleic acids were synthesized from simpler precursors and assembled into protocells.**

3. **Models for life. Establish replicating, catalyti systems capable of evolution, and construct laboratory models of metabolism in primitive living systems.**

4. **Genomic clues to evolution. Expand and interpret the genomic database of a select group of key microorganisms in order to reveal the history and dynamics of evolution.**

5. **Linking planetary and biological evolution. Describe the sequences of causes and effects associated with the development of Earth's early biosphere and the global environment.**

6. **Microbial ecology. Define how ecophysiological processes structure microbial communities, influence their adaptation and evolution, and affect their detection on other planets.**

Does life exist elsewhere in the Universe?

7. The extremes of life. Identify the environmental limits for life by examining biological adaptations to extremes in environmental conditions.

8. Past and present life on Mars. Search for evidence of ancient climates, extinct life and potential habitats for extant life on Mars.

9. Life's precursors and habitats in the outer solar system. Determine the presence of life's chemical precursors and potential habitats for life in the outer solar system.

10. Natural migration of life. Understand the natural processes by which life can migrate from one world to another.

11. Origin of habitable planets. Determine (theoretically and empirically) the ultimate outcome of the planet-forming process around other stars, especially as it relates to habitable planets.

12. Effects of climate and geology on habitability. Define climatological and geological effects upon the limits of habitable zones around the Sun and other stars to help define the frequency of habitable planets in the universe.

13. Extrasolar biomarkers. Define an array of astronomically detectable spectroscopic features that indicate habitable conditions and/or the presence of life on an extrasolar planet.

What is life's future on Earth and beyond?

14. Ecosystem response to rapid environmental change. Determine the resilience of local and global ecosystems through their response to natural and human - induced disturbances.

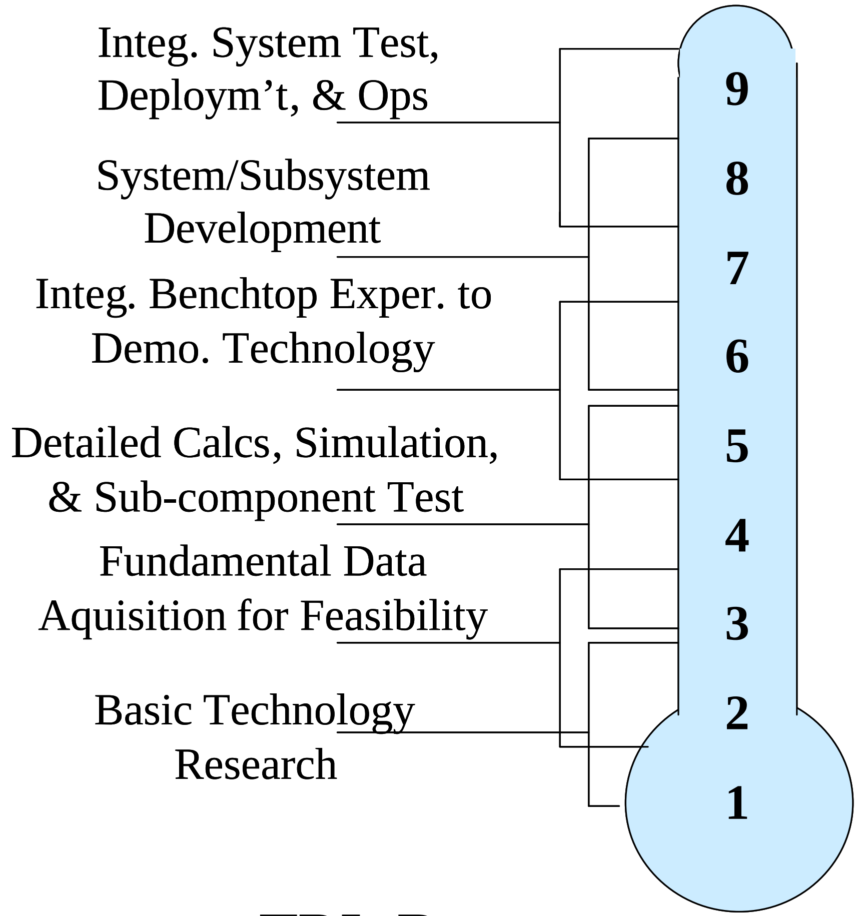
15. Earth's future habitability. Model the future habitability of Earth by examining the interactions between the biosphere and the chemistry and radiation balance of the atmosphere.

16. Bringing life with us beyond Earth. Understand the human-directed processes by which life can evolve beyond Earth.

17. Planetary Protection. Refine planetary protection guidelines and develop planetary protection technology for human and robotic missions.

Technical Readiness Level (TRL)

- Used by NASA to define the state of development for systems and subsystems



TRL Barometer

TRL Based Development Model

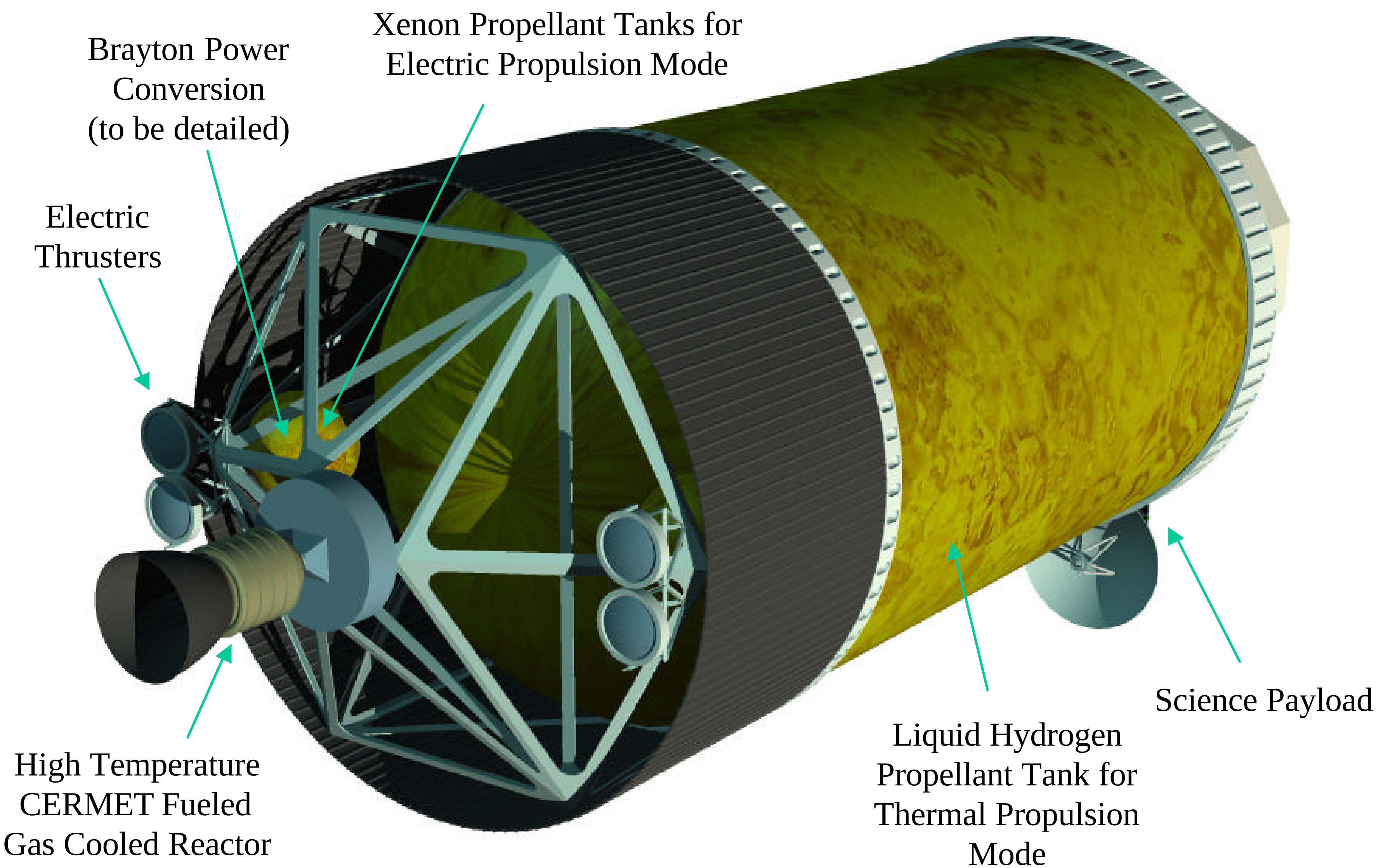
SAIC created log-normally distributed probabilistic models of development time for TRLs

TRL	Median Time to Development MTTD	Uncertainty Error Factor
1-3	10	15
2-4	7	10
3-5	5	7
5-7	3	5
6-8	2	3
7-9	1	1.5
10	Developed & Integrated	None

Achievability Model Implementation

TRL-	Median	Mean	95% tile	Achievability P(success at 5 Years)
1-3	10	40	150	33%
2-4	7	20	70	40%
3-5	5	10	35	50%
5-7	3	5	15	68%
6-8	2	2.5	6	91%
7-9	1	1.05	1.5	100%

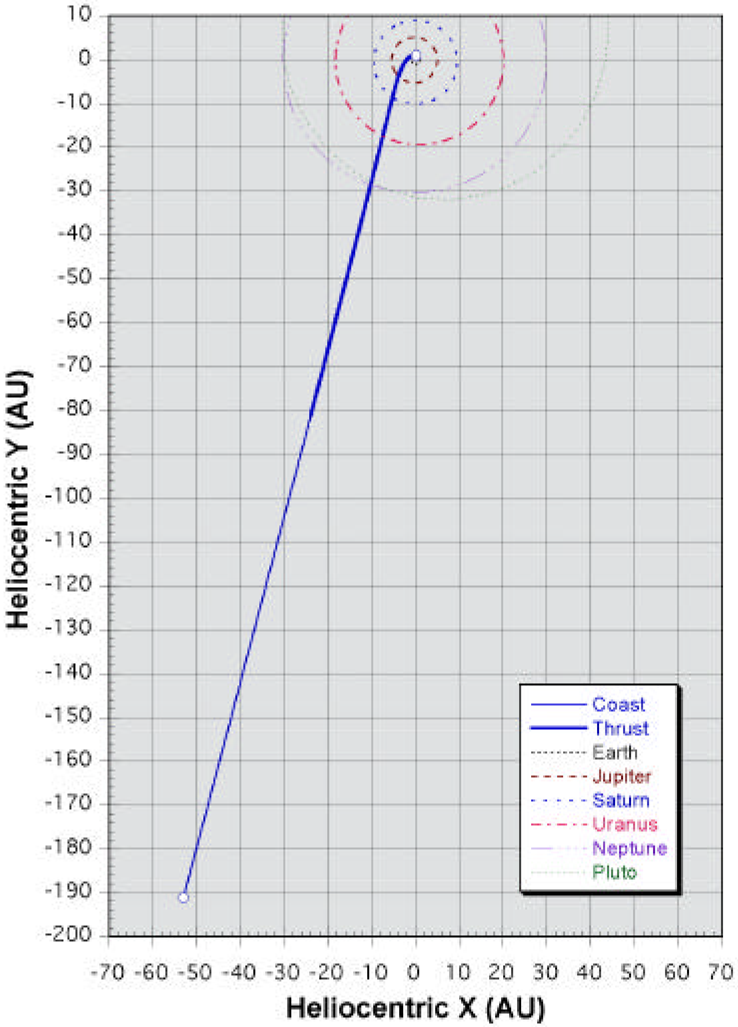
BNEP Concept: Scientific Probe To Neptune



Interstellar Precursor Scientific Probe

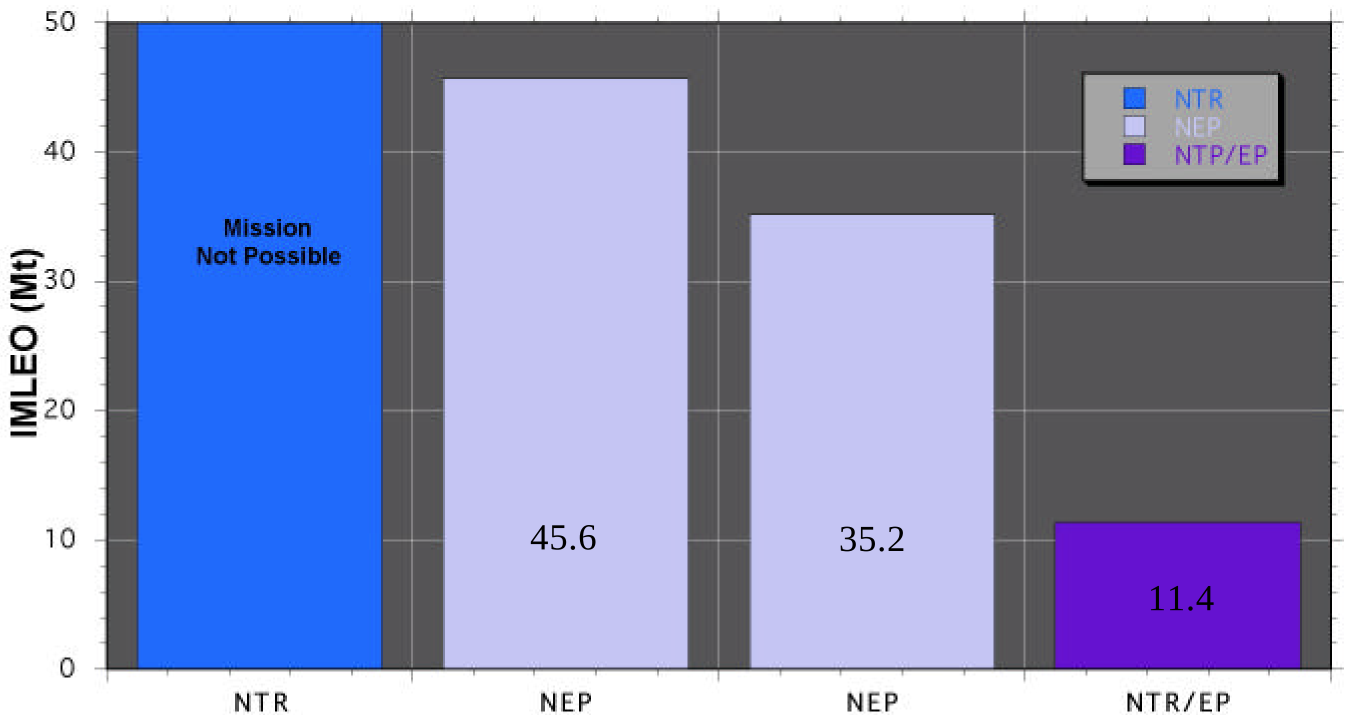
- **NASA Office of Space Science potential mission**
- **2015 Departure 20 years to 200 AU**
- **30 kg Science Package**
- **NEP:**
  - **Chemical Earth Escape from LEO (407 km Circular) to C3=100 km²/sec²**
    - Isp 466 sec, 88% Propellant Fraction
    - Jettison after TISI
  - **EP Acceleration to 200 AU**
- **NTP**
  - **NTR Earth Escape from LEO to C3=435 km²/sec²**
- **BNEP**
  - **EP LEO-HEEPO Spiral prior to Trans-Interstellar Injection**
  - **NTR Earth Escape to C3=100 km²/sec²**
  - **Jettison LH2 Tank after TISI**
  - **EP Acceleration to 200 AU**

High Energy Mission



Performance Comparison: Interstellar Precursor Scientific Probe

2015 Mission 20 Year Transit



NTR	NEP	NEP	NTR/EP
"Near-Term"	**"Near-Term" Technology Brayton**	**"Mid-Term" Technology Brayton**	**"Near-Term" Technology BNEP-Striling**
Isp 940 sec	Specific Mass 51 kg/kWe	Specific Mass 47 kg/kWe	Specific Mass 57 kg/kWe
	41 kWe	32 kWe	43 kWe
	Isp 11500	Isp 11500	Isp 11500/3000
	Chem Isp 466	Chem Isp 466	NTR Isp 940

Space Transportation Project Office
Glenn Research Center

Planned FY 2002 Activities (continued)

- **Human and Robotic Cooperative Teams Beyond LEO**
  - **Study Lead: Chuck Weisbin, JPL**
  - **Objective(s):**
    - Analyze human and robotic assets working jointly in space scenarios beyond Earth orbit
    - FY02 analysis will focus on in-space structure deployment as defined in FY 01 by the multi-center (JSC/JPL/ARC/LaRC/Hq) NASA Human-Robot Joint Enterprise Working Group

Planned FY 2002 Activities (continued)

- **Human and Robotic Cooperative Teams Beyond LEO (continued)**
  - Analysis will include:
    - Determination of optimal robot and human roles in space for range of mission scenarios ?
    - Identification of those tasks for which humans and/or robots are each critical; for what mission operations are humans so critical that the benefit compensates for risk and cost.
    - Identification of mission architectures and procedures to best combine human and robot roles in first-of-kind space operations.
    - Identification of technology gaps where neither human or robot technology meets anticipated requirements.
    - Quantification and analysis of performance for various human/robot system architecture options, as determined in controlled laboratory conditions.
    - Trades of various types of mission and system architectures, e.g.,
      - » Remote tele-presence, with human at a control station and robots operating in supervisory control at a remote location
      - » Cooperative task execution, with both humans and robots operating jointly at a remote location

Planned FY 2002 Activities (continued)

- **Advanced In-Space EVA Capabilities**
  - **Study Lead: Joe Kosmo, JSC [Original proposal submitted by Mary DiJoseph, HQ]**
  - **Objective(s):**
    - Develop designs for advanced EVA systems/spacesuits for highly-capable human operation in free space:
      - Undertake the development of multiple EVA system designs that achieve the goals of deploying, servicing, rescuing, repairing, and upgrading future major space facilities in free space
      - Alternative designs will be broad enough to include a range of human-enhancing capabilities: telerobotics from a station, ‘man-in-a-can’, etc
      - In all cases, optimized coordination with advanced robotics will be incorporated
    - Develop a technology investment/EVA capabilities ‘roadmap’ for the next two decades:
      - Develop a roadmap for free-space EVA that lays out an investment and development strategy and recommendations that would lead to enhanced human/robotic operation in space by the 2020+ timeframe

RASC EVA Study Progress

- Initial approval tentatively granted in mid August 2001 ($250K estimate)
- HQ enterprises notified of FY02 task selections via Oct 2 meeting and Oct 4 letter
- Responsibility reassigned from original HQ/GSFC contact to JSC in October-November
- Advanced EVA presentation made to human/robotic exploration workshop on Nov 6-7. Results are posted at http://www.icase.edu/workshops/hress01.html. Still waiting on receipt of CD of proceedings for consideration in EVA report
- Initial portion of RASC FY02 funds supplied to JSC in December 2001
- EVA study implementation plan routed in mid January 2002 (SAIC and Frassanito tentatively identified as task support contractors)
- Other tasks identified by LaRC reduced the EVA allocation to $125K in early Feb 2002
- $56.5K of allocated $125K segregated from 2 unrelated RASC tasks in late Feb 2002
- Readily available technical information provided to SAIC in February and March
- Procurement paperwork filled out and funds made available to support contractors in late March 2002 ($20K to JF&A, $36.5K to SAIC).
- Plans in work to solicit inputs from academia, industry and NASA centers. ARC/JSC robotics state of the art questionaire obtained for EVA study customization and email distribution. Adaptation and reuse of ARC website was found to not be practical or sufficiently useful (too much time and labor - not free to non-ARC customers)
- Remaining balance of funds not yet received at JSC
- Since this effort is only in the early stage of development, no significant progress can be reported other than the above mentioned planning and coordination activities

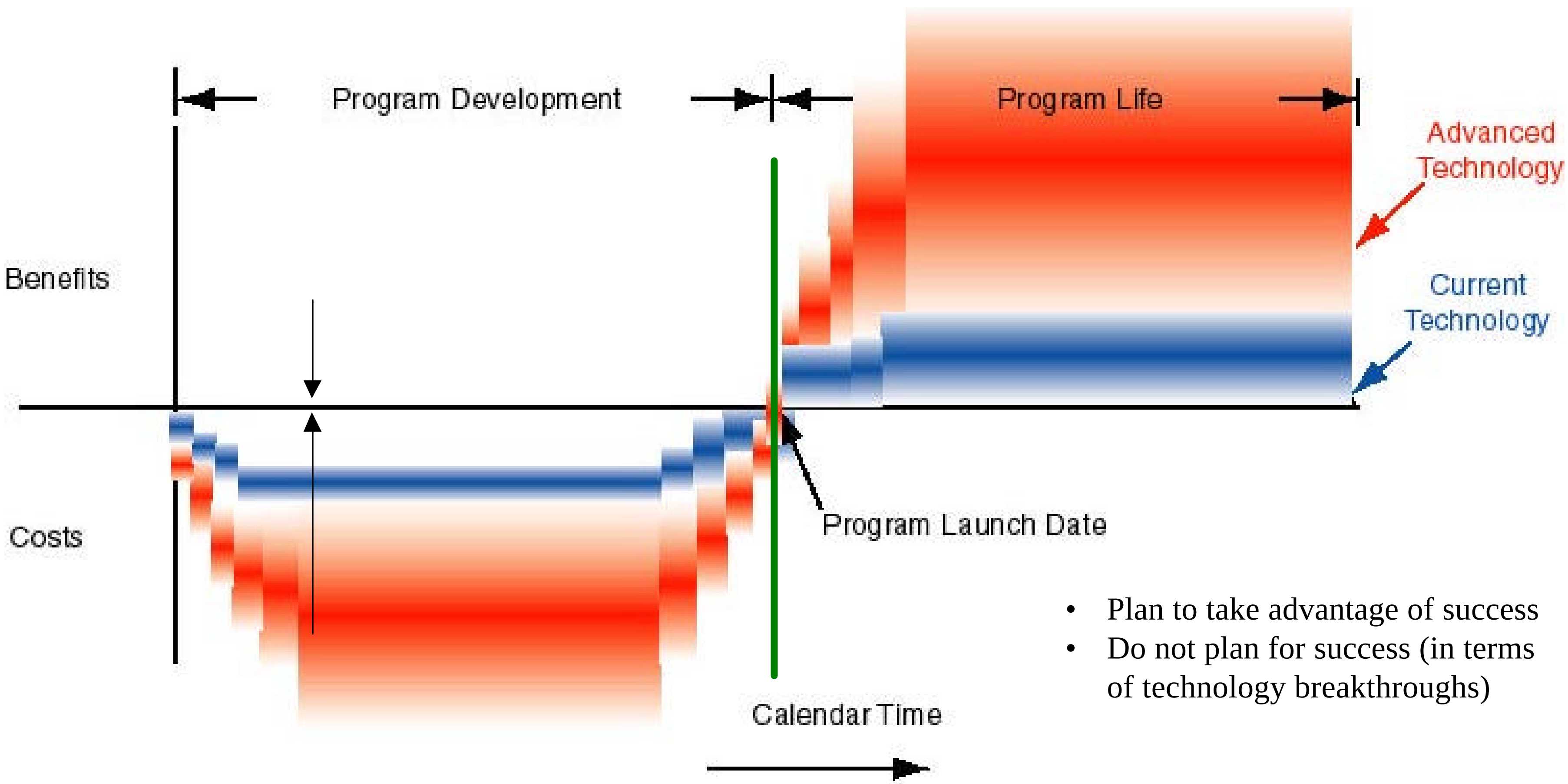
Planned FY 2002 Activities (continued)

- **Human Emplacement of Lunar Telescopes**
  - **Study Lead: Mike Duke, CSM [Original proposal submitted by Harley Thronson, HQ]**
  - **Objective(s):**
    - Assess how effectively astronomical telescopes would work on the Moon
      - Critically examine telescopes on the surface of the Moon in terms of:
        - » Environmental limitations to sensitive operation on the surface of the Moon compared to free space
        - » Technological solutions which might mitigate these limitations
        - » Identification of operational constraints for surface and free-space operation of astronomical observatories
        - » Based on the science priorities of the Office of Space Science, this study would concentrate on ultraviolet, visual, and infrared wavelengths
        - » Assess siting telescopes in unique locations, such as shadowed craters near the lunar poles, or other special situations that could use the environmental properties of the Moon in novel ways for emplacement of telescopes

Planned FY 2002 Activities (continued)

- **Human Emplacement of Lunar Telescopes (continued)**
  - Assess the optimum designs for large astronomical telescopes on the Moon's surface
    - Designs for complex scientific facilities on the Moon's surface or elsewhere are likely to depend strongly upon the techniques used for construction, repair, and servicing
    - Assess the problems of fabrication, transportation, erection, and operations of a telescope on the Moon and identify the technology capabilities needed to overcome the challenges
    - Characteristics to be considered are:
      - » Expected performance of the lunar telescope
      - » Operational concept for deploying the instrument on the Moon, optimally using humans and machines to assemble the instrument
      - » Operational concept for repairing or upgrading the instrument, including roles of humans and robots
      - » Transportation cost for moving the telescope from Earth to the Moon's surface

Benefit Return of Technology Investment



- Plan to take advantage of success
- Do not plan for success (in terms of technology breakthroughs)

Typical Investment Cost Benefit Streams (Undiscounted)
for
Current and Advanced Technology

Note Advanced Technology "Promises" higher return for greater investment but the return has greater uncertainty